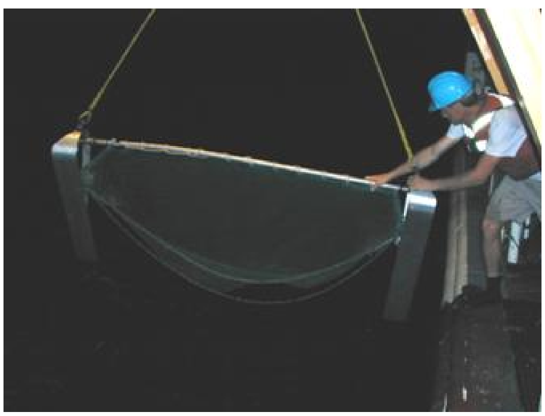
Ongoing Monitoring of Tortugas Ecological Reserve: Assessing the Consequences of Reserve Designation



NOAA Technical Memorandum NOS NCCOS 22

Ongoing Monitoring of Tortugas Ecological Reserve: Assessing the Consequences of Reserve Designation

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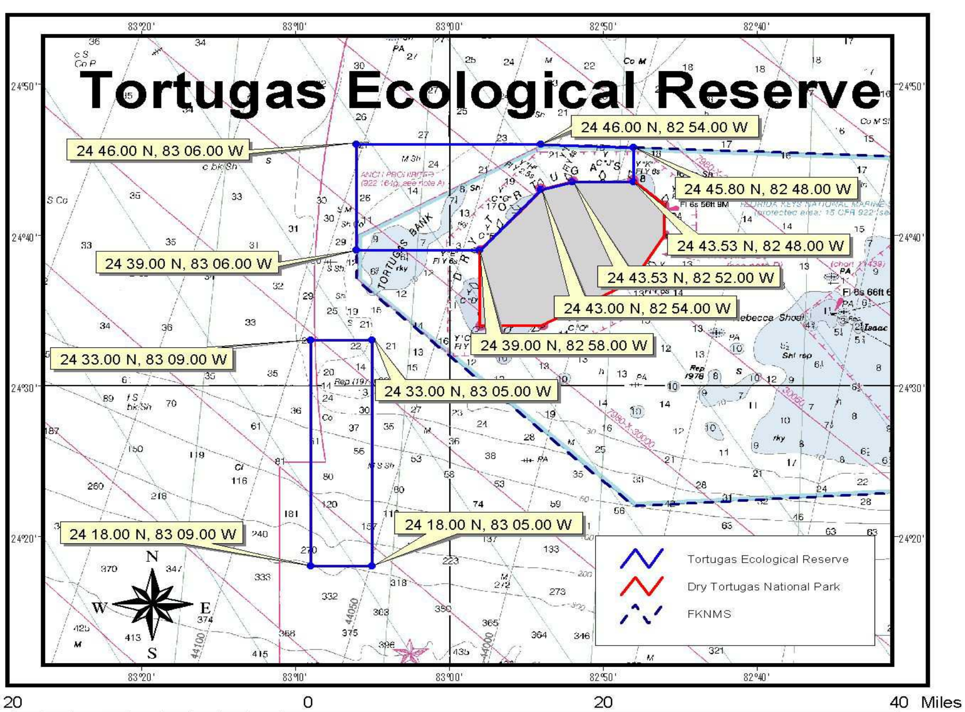
Abstract

Over the past five years, a biogeographic characterization of Tortugas Ecological Reserve (TER) has been carried out to measure the post-implementation effects of TER as a refuge for exploited species. Our results demonstrate that there is substantial microalgal biomass at depths between 10 and 30 m in the soft sediments at the coral reef interface, and that this community may play an important role in the food web supporting reef organisms. In addition, preliminary stable isotope data, in conjunction with prior results from the west Florida shelf, suggest that the shallow water benthic habitats surrounding the coral reefs of TER will prove to be an important source of the primary production ultimately fueling fish production throughout TER. The majority of the fish analyzed so far have exhibited a C isotope signature consistent with a food web which relies heavily on benthic primary production. Fish counts indicate a marked increase in the abundance of large fish (>20 cm) within the Reserve relative to the Out and Park strata, across years. Faunal collections from open and protected soft bottom habitat near the northern boundary of Tortugas North strongly suggest that relaxation of trawling pressure has increased benthic biomass and diversity in this area of TER. These data, employing an integrated Before - After Control Impact (BACI) design at multiple spatial scales, will allow us to continue to document and quantify the post-implementation effects of TER

Introduction

On July 1, 2001, the nation's largest marine Ecological Reserve was designated in the Dry Tortugas. Approximately 70 miles west of Key West, Florida, the Tortugas Ecological Reserve (TER) encompasses 151 square nautical miles and is composed of two separate areas: Tortugas North and Tortugas South (Figure 1). Tortugas North, located west of Dry Tortugas National Park (DTNP), covers the northern half of Tortugas Bank, Sherwood Forest, the pinnacle reefs north of the bank, and extensive low relief areas in the 15 - 40 m depth range (Figure 1). Although this area remains open to SCUBA diving (phone-in permit required), the taking of any marine life is prohibited. In addition, strict regulations have been imposed regarding vessel discharges and anchoring/mooring. Tortugas South, located to the southwest of DTNP, includes Riley's Hump, a large, ~ 30 m deepwater mount, as well as deepwater (~ 700 m) habitats to the south (Figure 1). Recreational SCUBA diving in Tortugas South is prohibited, as is the taking of



This chart and these coordinates are for informational purposes only and are not intended for navigational use.

Figure 1. Boundaries of Tortugas Ecological Reserve.

any marine life. Vessels must remain in transit through this area, with the exception of Sanctuary-permitted research vessels. Based upon published information and interviews with experienced commercial fishermen, Riley's Hump has been identified as a potential spawning site for five commercially important snapper species (Lindeman et al., 2000). Other commercially important species are supported by the deepwater regions of Tortugas South, including snowy grouper, golden crab, and tilefish.

The need for detailed habitat characterization is inextricably linked with the issue of selecting a reserve location and this is incorporated in a biogeographic assessment. Biogeography simply focuses attention on what ecologists have implicitly known for many years: the geographic context of the biota not only signal the organization of ecosystem processes, but in many instances, act to control or strongly modify those processes. In other words, to examine living organisms without regard to their spatial and temporal organization at multiple scales of organization, and in association with physical factors (i.e., sediment grain size, sediment nutrient content) will fail to elucidate vulnerability, susceptibility, and resilience of the ecosystem. For example, by leaving the structure of the reef at night to forage in adjacent sand, algae, and seagrass flats, many reef fishes import significant amounts of nutrients onto the reef environment, thereby contributing to its high productivity (Meyer et al., 1983). This mass transfer also ultimately contributes to energy requirements of small grazers that cannot access the adjacent, non-coral reef resources. Adjacent seagrass beds are also significant settlement areas for post-larval reef fishes. Over-fishing of the diurnally migrating fishes and/or physical damage to the foraging/settlement environment could significantly alter productivity and biological diversity in TER. Therefore, habitat characterization is critical in determining the distribution of sessile resources which are susceptible to injury and which may recover from damaging activities following implementation of the Reserve.

The protection afforded by Reserve status provides a unique opportunity to examine the refuge effect in a marine system on an unprecedented scale. More specifically, conducting work in TER provides a unique opportunity to compare the structure and function of a relatively undisturbed system with that elsewhere in the FKNMS and adjacent waters. This comparative approach has significant potential for direct application to management issues in other NOAA trust resources. Therefore, findings from this study will have significant value for consideration of Marine Protected Areas (MPA) elsewhere in NOAA's jurisdiction.

Within our Center, multiple cruises, utilizing three different NOAA ships, have been conducted in support of this research (Table 1). The ultimate goal of this program is to provide a measurement of the refuge effect of TER. To achieve such an assessment, the following areas of concern were identified as focal points for research: 1) improved habitat characterization; 2) specialized exploration of deep (> 100m) areas and their characterization; 3) determination of biological boundaries; 4) spillover/larval export effect; and 5) effectiveness of a large MPA in supporting ecosystem recovery. In this Technical Memorandum, we focus on points 1, 3, and 5 in a comparative context among the three management zones: DTNP, TER, and areas outside these protections.

Methods

Experimental Design

<u>2000</u>: In the summer of 2000, a year before TER was established, the area within and outside the proposed Reserve was divided into two strata, Use and Depth. Use was broken down into the existing DTNP (Park), the proposed Reserve (not falling within the existing jurisdiction

Table 1. Completed research cruises in chronological order.

Cruise Name	Dates	Vessel	Sea Days	# Dives
FE-00-09-BL	7/10/00 - 8/4/00	NOAA Ship *FERREL*	20	164
OT-01-01	1/4/01 - 2/13/01	NOAA Ship *OREGON II*	8	0
FE-01-07-BL	4/8/01 - 4/20/01	NOAA Ship *FERREL*	12	55
FE-01-10-BL	6/17/01 - 7/1/01	NOAA Ship *FERREL*	13	111
FE-01-11-BL	7/8/01 - 7/21/01	NOAA Ship *FERREL*	13	86
GU-01-03	7/2/01- 7/3/01	NOAA Ship *GORDON GUNTER*	2	0
Charter	5/11/02 - 5/13/02	*F/V Alexis M*	3	1
Charter	5/27/02 - 5/30/02	*F/V Alexis M*	4	12
Charter	6/6/02 - 6/12/02	*F/V Alexis M*	4	9
Charter	6/23/02- 6/26/02	*F/V Alexis M*	4	10
FE-02-14-BL	6/17/02 - 7/12/02	NOAA Ship *FERREL*	24	184
FE-02-15-FK	7/15/02 - 7/19/02	NOAA Ship *FERREL*	5	49
Charter	7/23/02 - 7/26/02	*F/V Alexis M*	4	13
Charter	10/20/02 - 10/23/02	*F/V Alexis M*	4	8
NF-03-04-FK 013	07/07/03 - 07/19/03	NOAA Ship NANCY FOSTER	12	195
NF-04-16-FK Charter	09/21/04 - 09/30/04	NOAA Ship NANCY FOSTER F/V *Alexis M*	10	142
NF-05-15-CCFHR	08/01-05 - 08/12/05	NOAA Ship NANCY FOSTER	12	259
		TOTAL DAYS AT SEA	**154**	
		TOTAL # DIVES		**1298**

of the DTNP), and a 5 km buffer around the proposed Reserve not within the DTNP (Out) for before/after comparisons. Within each Use category, three depth strata were arbitrarily defined as: 0 - 15 m (shallow); 15.1- 30 m (intermediate); and > 30.1 m (deep). The entire sample universe was broken into 1 km square grids which were randomly chosen from within each stratum for sampling. Precise sample locations from within each square km were also randomly chosen at 1m resolution through additional sub-sampling and locating of coordinates in the field by use of DGPS (Trimble GPS Pathfinder® Pro XR/XRS). At each sample point, we conducted extensive benthic habitat mapping using a MiniBAT® tow body (Figure 2) housing a downward facing SeaViewer® color Sea-Drop camera to videotape the seafloor at 5 -8 m resolution. Video was recorded onto either digital, SVHS, or VHS tapes and the exact time and location along each transect was stamped onto the video using the Horita® GPT-50 GPS video titler linked to a Trimble GPS Pathfinder Pro XR/XRS. Track lines were recorded using Trimble ASPEN® software. Three parallel passes of approximately 1 km in length and separated by a distance of ~ 200 m were made at each point, running parallel to the reef face.

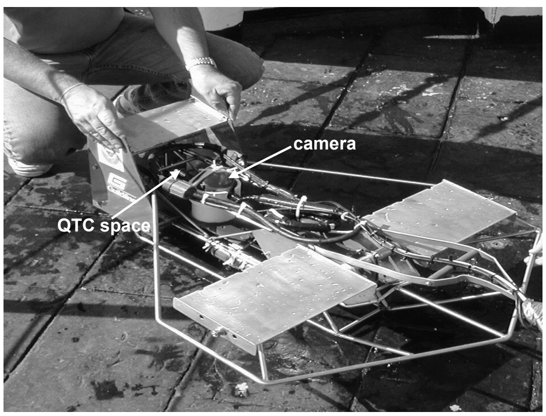


Figure 2. MiniBAT® tow body.

We discovered that there was unequal representation of Depth strata among the three Use strata, which would lead to an unbalanced sampling design. Specifically, depths within DTNP were too shallow to encompass all three depth strata. As such, we chose to adopt a sampling protocol that focused on habitat interfaces (i.e., areas where coral reef meets seagrass/algal plain) using randomly selected, permanent transects, rather than concentrating on differences in depth. Our video and drop camera (video camera attached to a fixed framework and lowered from a small launch) work from this year detailed the extensive areas of potential sand-coral interfaces, essentially running around the entire perimeter of Tortugas Bank and DTNP.

The decision to focus sampling at the habitat interface was based upon several ecological considerations. The interface, or *ecotone*, is used in two fundamental ways in sampling designs. One approach is to use boundaries as ways to stratify sampling, thereby limiting sampling to within a certain class of conditions (e.g., habitat type) and reducing sample heterogeneity. The other approach is to focus on the boundary itself, especially when the exchange or movement of resources (e.g., propagules, migrating fauna, energy, nutrients, etc.) is of special interest. We have taken the latter approach because these boundaries are not absolute and we hypothesize that energy flow across these boundaries is critical to understanding changes among strata as a result of Reserve implementation. We pose this hypothesis because previous stable isotope analysis work on the west Florida shelf has revealed that production of fishes, including individuals captured on hard bottom areas, is driven by benthic micro- and macroalgae and the deep water seagrass, *Halophila decipiens* and not phytoplankton as previously believed. Given that over 70% of TER is non-coral habitat, these findings further strengthen the idea that the areas surrounding the coral formations are a critical source of energy for the maintenance of the coral reef ecosystem. Finally, considering that predation is often high in low relief areas, especially at interfaces, the structure and composition of fish communities near these interfaces, along with the structure of the physical landscape, should be areas where any changes resulting from Reserve implementation fast become evident.

Given that we have no independent replication at the Use strata level, we adopted a Before - After Control-Impact (BACI) sampling strategy (Underwood, 1991). We have the added advantage of not only the unaltered, Out strata as a comparative sample (BACI control), but also the Park as a long-term control and potential comparative sample representing a mature community, free from consumptive harvesting impacts. With the permanent transects in place and time zero data in hand ("before"), the "after" assessments and documentation of the efficacy of TER can be completed.

2001-2004 : The random selection of permanent transects allowed us to stratify sampling by using the previously defined Reserve, Park, and Out strata. In addition, lines were drawn through the longest axis of Tortugas Bank and DTNP, normal to the prevailing northwest-southeast currents and bisecting these features into areas facing either upstream (North) or downstream (South; Figure 3). Thus, the interface zones along both of the large reef structures in Tortugas North (Tortugas Bank and DTNP) were designated as one of six categories: 1) Out North; 2) Out South; 3) Park North; 4) Park South; 5) Reserve North; and 6) Reserve South (Figure 3).

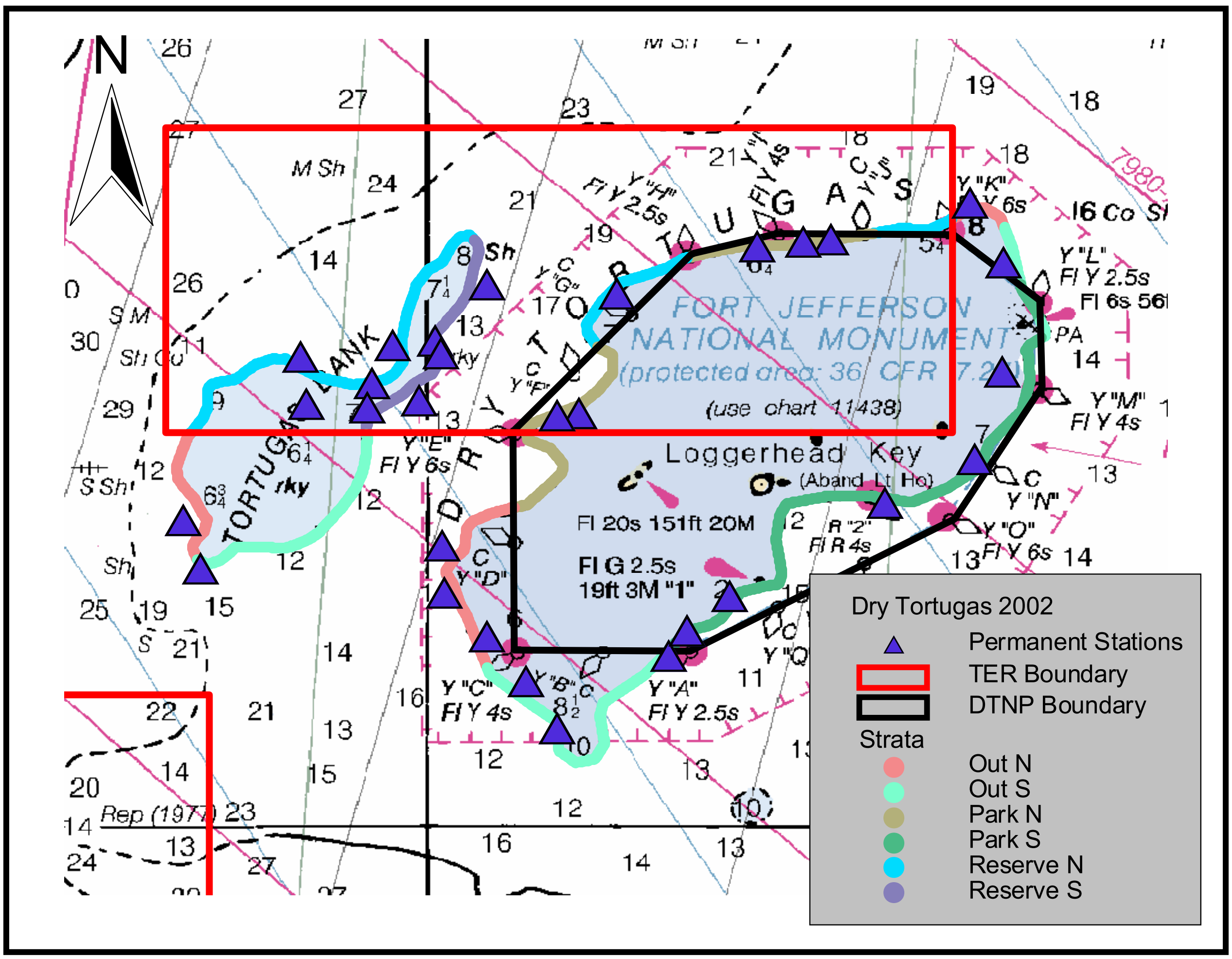


Figure 3. Location of interface strata and 30 permanent stations.

To choose the five random transects from within each of the six categories, we used ESRI's ArcInfo® software and imposed a line at roughly the 10 fathom isobath around the perimeter of the two large coral platform features, as this roughly approximated the location of the sand-coral interface. Each line was then broken down into the aforementioned six categories and random locations, 50 m apart along each line type, were selected. It was estimated that 50 m would allow for visual isolation of potentially adjacent sites, an important factor for our fish visual census method. The selection of random locations along each line type was continuous across the entire landscape, even though line types were segmented among the two large coral platform features, yielding true randomization.

Sampling Approach

Fine-Scale Mapping : From 2001 – 2005, detailed mapping of benthic composition was conducted at sub-centimeter resolution at each permanent station. Divers were deployed at each permanent station to conduct video transects of benthic habitat and coral presence/absence surveys. Small launches navigated to each station using DGPS (Trimble GPS Pathfinder Pro XR/XRS). Coordinates for each interface had been recorded during previous mapping operations. Divers operating from the launch established semi-permanent rebar stakes at each interface. A surface float attached to the stake was released by the divers and the location of the float was recorded topside using DGPS. When previously installed markers were not located at the specified drop point, divers searched the area for approximately five minutes. If the marker was found to be > 20 m from the drop point, a surface float was deployed at the marker and a new coordinate was recorded by personnel at the surface using DGPS. If the search revealed no marker, a temporary marker (rebar stake) was installed and removed at the end of dive activities.

Divers followed transect lines beginning from the permanent/temporary marker at the interface and running 30 m out in either direction, perpendicular to the interface (sand plain vs reef). One diver used a digital video camera (SONY DCR TRV900/1000 MiniDV Handycam® camcorder) contained in an underwater housing with lighting unit, to record the substrate along the length of each transect. Video collection techniques are based on those used by the Coral Reef Evaluation and Monitoring Project (CREMP) at Florida Wildlife Research Institute. The camera unit was equipped with a measuring device that the diver used to determine and maintain a fixed distance off the bottom. In 2001, the camera was fixed at 1m. Base on preliminary analyses, it was determined that this distance was too far to allow accurate species identification. Thus, in 2002, the camera was lowered to 40 cm which allowed the video image to span a fixed 0.16 m^2 area. Videographers swam at speeds around 4 meters per minute. A SENSUS PRO (ReefNet) dive data recorder was affixed to the camera housing and a continuous depth profile for the duration of the video transect was collected. Data from the SENSUS PRO were downloaded after each dive and were used to calculate one measure of reef rugosity (surface topography). Due to the intensive, time consuming nature of video frame-grabbing , digital still photography (Olympus C-8080 Zoom digital camera in an Ikelite underwater housing) replaced the video method in 2005. Photos were taken at 0.5 m intervals at the same fixed distance as reported above.

Habitat cover along each transect was determined using CREMP's custom software application, Point Count for Coral Reefs (Wheaton et al., 2001). While examining transect video playback, video frames that abut, with minimal overlap between frames, were manually selected by the viewer, and still images were "grabbed" using DVgate or Sony's Pixella software (bitmap photos). On average, 75 images per transect were grabbed (frame width of 40 cm). These images were uploaded into Point Count. The software overlaid ten random points per image which were then classified to the appropriate habitat taxa (Table 2). Any sign of coral disease or other abnormalities were noted in the program's comments option. Point classifications for each transect were then imported into SAS and analyzed for benthic cover.

To provide an additional index of substrate complexity, rugosity along each reef transect at each station was quantified in 2003 using the chain-and-tape method (McCormick, 1994). A small link chain of known length (30 meters) was draped over the reef, following along the transect line. Care was taken to ensure that the chain was pushed into all indentations and crevices. The linear distance that the chain covered was measured against the transect tape. Rugosity was calculated following McCormick (1994) where,

Rugosity = (*in situ* linear distance of draped chain) / (total length of chain).

Using this formula, a flat reef surface would have a value close to 1; whereas, a highly complex, contoured reef would result in an index approaching 0.

<u>Coarse-Scale Mapping</u> :

Towed Video/Sonar: As part of our design to compare differing scales of habitat characterization, we conducted more detailed benthic habitat mapping of the 30 stations during 2001 - 2002. In order to provide a more geographically balanced survey (which facilitates geospatial analysis required by our characterization plan), mapping was conducted at each permanent station by making 0.25 nautical mile "S" turns with the MiniBAT at the interface between sand and coral, running parallel to the depth contour and normal to the initial, three parallel track lines. In 2002 and 2003, we mapped the stations using an additional device, the Sport Scan® sidescan sonar unit. Again, the location of the reef/sand plain interface within the vicinity of the station coordinate was determined using the ship's fathometer. A maximum of

Table 2. Habitat categories used in video analysis.

Habitat Category	Description	
Unconsolidated Substrate	Any unconsolidated sediment including: sand, clay, & mud	
SAV	All macroalgae & seagrass species including:	
	Dictyota spp. *Halimeda spp.* *Lobophora spp.* Macroalgae *Udotea spp.*	*Thalassia testudinum* *Halodule beaudettei* *Halophila decipiens* *Syringodium filiforme*
Rock/Rubble	Any non-living, solid substrate available for settlement by other organisms including: dead coral, mollusk shells, and rock.	
Sponge	All Porifera	
Octocoral	Any species of subclass Octocorallia including: all Gorgonians, Telestaceans, and Soft Corals.	
Scleractinia	All stony corals from subclass Hexacorallia including:	
	Acropora cervicornis *Agaricia agaricites complex* *Agaricia fragilis* *Agaricia lamarcki* *Colpophyllia natans* *Dichocoenia stokesii* *Diploria clivosa* *Diploria labyrinthiformis* *Diploria strigosa* *Eusmilia fastigiata* *Madracis decactis* *Meandrina meandrites* *Montastrea annularis complex*	*Montastrea cavernosa* *Mycetophyllia aliciae* *Mycetophyllia danaana* *Mycetophyllia ferox* *Oculina diffusa* *Porites astreoides* *Porites porites* *Scleractinia* *Scolymia cubensis* *Siderastrea radians* *Siderastrea siderea* *Solenastrea hyades* *Stephanocoenia michelinii*
Fire Coral	Any species within the family Milliporidae, including: *Millepora alcicornis* and *Millepora complanata*	
Other Invertes	Other invertebrates not previously identified or of particular concern including: *Diadema antillarium* and *Condylactis gigantea*	
Unknown	Any unclassifiable point, typically due to poor image quality or dark area, such as a crevice, with insufficient light.	

three parallel tracks (~ 500 - 1000 m long) were made at each station, running parallel to the reef-sand ecotone. On several occasions, the MiniBAT was run simultaneously with the Sport Scan as a means of better interpreting the sonar images.

Track line files generated in ASPEN were exported to Microsoft® Excel. The times and coordinates displayed on the videos correspond to the chronologic records in the ASPEN-generated Excel spreadsheet. While the video is playing, Center for Coastal Fisheries and Habitat Research (CCFHR) staff record a habitat code every five seconds based upon what is viewed in the video frame at that time. The track line spreadsheet, complete with habitat classification, is converted to a text file and imported into ESRI's ArcView® software. In ArcView, the habitat codes are assigned unique color values. The color-coded track lines are then displayed on a chart of the Dry Tortugas, effectively creating a habitat map of the area (Figure 4).

Aerial Photography: The coral, algae, and seagrass habitats of the Dry Tortugas have been mapped only once in recent times, using color aerial photography from 1991. Due to the scale of the photography (1:48,000) and water quality conditions at the time, considerable habitat was left unmapped. In fact, GIS-based comparisons of habitat characterization of the deepwater edge of the DTNP reef system by CCFHR using sidescan sonar and underwater video, has indicated that the 1991 site characterization, which utilized aerial photography and ground truthing, underestimated coral habitats by at least 28 percent. These data indicate that remote sensing with aerial or orbital platforms alone is not adequate to characterize the full extent of this reef system.

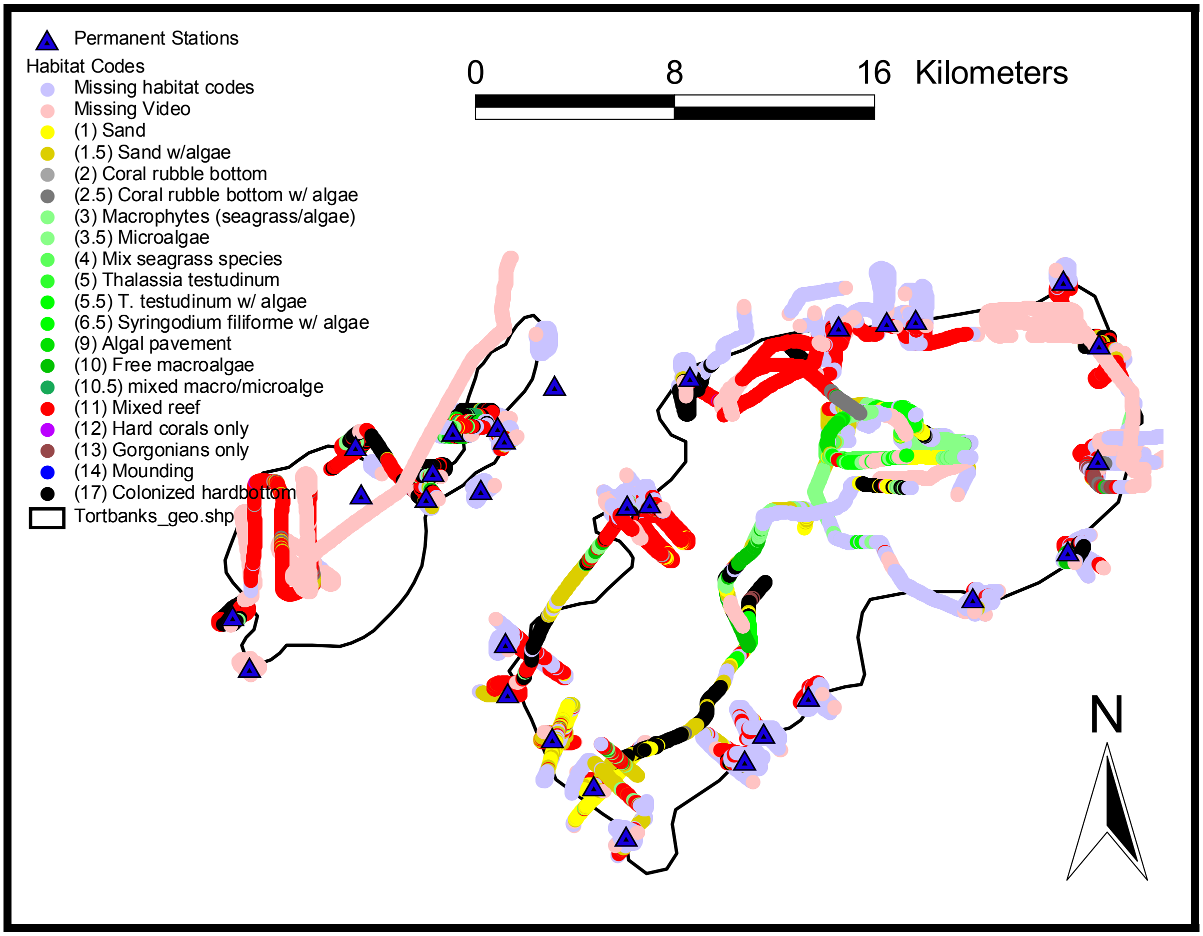


Figure 4. Track lines with habitat classification from 2000 - 2004 MiniBAT transects.

CCFHR, in cooperation with NOAA's Coastal Services Center, is undertaking a remote sensing effort aimed at updating the 1991 base map, and examining the scale and depth limitations of various remote sensing platforms. CCFHR has acquired several new remotely sensed data sources to aid in this project including new aerial photography for the entire DTNP (April 18, 2003) and an IKONOS satellite image (April 9, 2001) and QuickBird satellite image (December 24, 2003) for the area around Fort Jefferson.

In 2002 and 2003, over three hundred random points were visited in the area surrounding DTNP for use in ground truthing activities. Using a small launch, we navigated to each point and lowered a tethered underwater video camera. Notes were made on the habitat type encountered and the depth and position was recorded. These observations will serve as accuracy assessment data for map products created from the aerial photography and the satellite data. All of these image sources will be compared to the 1991 aerial photos and in situ data collected by SCUBA divers, sidescan sonar, and underwater video, to evaluate what managers can expect from different scales of data and remote sensing platforms.

Simrad EM3000 Multibeam Echosounder: In 2004, Geodynamics was contracted to perform multibeam sonar surveys in order to obtain high-resolution hydrographic surveys of the 30 permanent stations. A Simrad EM3000 multibeam echosounder was employed to collect spatially dense bathymetric data and snippet data for each of the 30 permanent stations. The EM3000 transducer was secured using a mounting pole off the ship's starboard side approximately 4 m below the water's surface. The sonar system produced a swath of sonar approximately 3.5 to 4 times the water depth, collecting approximately 400 soundings per square meter.

<u>Sediment Characterization</u>:

While conducting habitat transect videos in 2001, divers collected sediment cores (3 cm diameter) at three distances (0 m, 15 m, and 30 m) along the 30 m sand transect at each permanent station. Core samples were analyzed for sediment particle size.

<u>Food Web Analysis</u>:

During each cruise, we collected flora and fauna for use in a multiple stable isotope analysis of the food web supporting fish production in TER. Samples collected from within the permanent stations included primary producers (phytoplankton, benthic microalgae, benthic macroalgae, and seagrass) and secondary consumers (fish, crabs, and shrimp). Several methods of collection were employed including hook and line from the research vessel, divers armed with sling spears, beam trawls, hand collection by divers, and bucket/Niskin Bottle casts. This sampling targeted the reef interface zone.

Microalgae Biomass:

From 2000 through 2005, samples for benthic and water column chlorophyll analysis were collected to estimate the biomass of benthic and planktonic microalgae within the three strata (Out, Park and Reserve). Samples were collected in July/August of each year except in 2001 during which samples were also collected during the winter and spring and in 2004 when samples were only collected during the fall. This data aids in our interpretation of stable isotope analysis of TER food webs, and also provides an additional environmental baseline in which we may be able to detect changes as a result of the imposition of TER.

In shallow waters (< 35 m), which characterized the majority of sites, benthic chlorophyll samples were diver-collected from the reef interface at each of the 30 permanent stations using small (1.1 cm diameter) syringe-cores, while in deeper waters (> 35 m) surface sediments were collected with a Ponar grab sampler. In 2000 and 2001, diver-collected sediments from the permanent stations were collected only at the reef/sand interface. In subsequent years, cores were collected from transects swum out from the interface to distances ranging between 15 and 500 m. The majority of the benthic samples were collected from the interface (0 m), and at plots 15 and 30 m away from the interface along the sand bottom. Chlorophyll was measured from the top 1 cm of each core, and from the 1-3 cm depth layer. In a few instances, deeper sediments were also analyzed. Sediment samples for chlorophyll analysis were extracted with methanol:acetone:water (45:45:10) and chlorophyll was measured spectrophotometrically.

Surface water samples were collected utilizing bucket casts or Niskin bottles. Subsurface, or bottom water samples, were collected with a Niskin bottle approximately 1 m above the sediment layer. Samples were filtered through a GF/F filter, extracted with acetone, and chlorophyll was estimated by fluorometry. Nutrient concentrations were measured on a subset of the water samples.

Fish Surveys:

Visual Census: Each year (2001-2005), divers conducted 30 m band transect fish counts at each of the 30 permanent stations, first along the reef transect followed by a census along the sand transect. Fishes were counted at two scales depending on their size and habits. Small, sedentary, reef and sand dwelling species were counted along a 2 x 30 m band and larger, vagile species were counted along a 10 x 30 m band. All fishes encountered in these bands were visually identified to species or the lowest taxonomic group possible. Visual identification of fishes was based on criteria provided by Humann and Deloach (2002) and their system of common and scientific names was followed. Species and species groups were counted in terms of the number that corresponded to length intervals. Intervals included 1-2, 2-3, and 3-5 cm and progressed in 5 cm intervals until the 30-35 cm interval. Lengths of fishes greater than 35 cm were tallied in a separate category and lengths estimated.

Fish counts were summed across size categories to provide total species and taxonomic group counts and across size and taxonomic categories to provide a total count of fishes observed for each reef and sand transect. Similarly, total counts of fishes of different length intervals were calculated by summing counts that fell within specified length intervals.

Simrad EQ60 Echosounder: Simrad EQ60 echosounder surveys, estimating the movement of fish biomass across TER reef habitat, were collected continuously throughout the

2004 cruise (Figure 5). The transducer was deployed in a through hole at midship. Initial data analyses will focus on surveys run simultaneously with the multibeam transects through all 30 stations, with special attention toward selected sites for day-night comparisons.

Gear Impact:

Beam Trawl: Along the northern boundary of Tortugas North, pairs of randomly selected coordinates (inside and outside Tortugas North) were chosen for beam trawl samples in 2001 – 2003 (Figure 6). The coordinates served as starting points for the trawl tow path and were located ~2 km on either side of the Tortugas North boundary. We conducted three minute tows at each coordinate using a modified 2 m beam trawl with a 3 mm mesh cod end. Samples were sorted and initially preserved in formalin (24 h) and then transferred to ethyl alcohol. The path of each trawl was recorded using ASPEN in order to verify the location of the surveys and certify that they were in either open or closed areas.

Drop Camera Drifts: In conjunction with the beam trawls, drop camera and ROV drifts were made in an effort to capture a video record of trawl disturbance. Fifteen minute drifts were made at the same coordinate pairs as the beam trawls. The path of each drift was video recorded and the track was recorded using ASPEN. Trawl tracks were evident on several occasions. Video processing is currently underway at CCFHR using the same methods as described under Coarse-Scale Mapping.

Results and Discussion:

Fine-Scale Mapping:

Mean rugosity for all strata approached 1.0, indicating that perhaps the reef surface topography at our sites is minimally rugose (Table 3). Differences in rugosity among strata were tested with ANOVA followed by Tukey's multiple comparison test. There was a significant

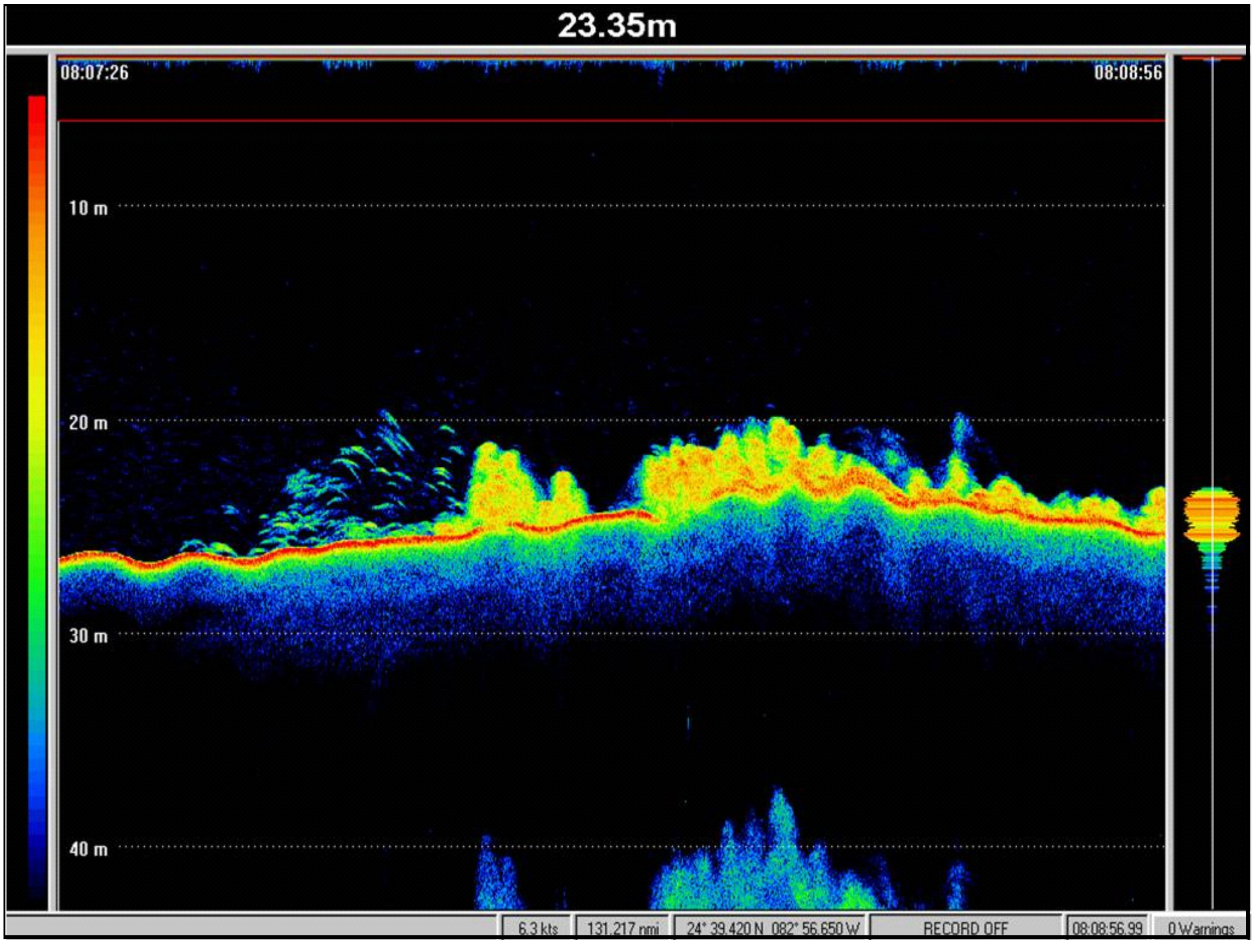


Figure 5. Simrad EQ60 snapshot depicting a large aggregation of fish near station PN3120. The red line demarcates the sea floor with reef rising above it.

Table 3. Mean rugosity ratio (+/- S.E.) for each strata. Strata with the same letter designation are not significantly different at alpha = 0.05.

Strata	**Mean Rugosity Ratio (S.E.)**	**Tukey's Multiple Comparison**
Out	0.8496 (0.02)	A
Park	0.7853 (0.03)	AB
Reserve	0.7235 (0.03)	B

strata effect (p = 0.02), with rugosity of Park and Out stations not significantly different from one another and Reserve rugosities significantly lower than Out stations but not significantly different from the Park (Table 3).

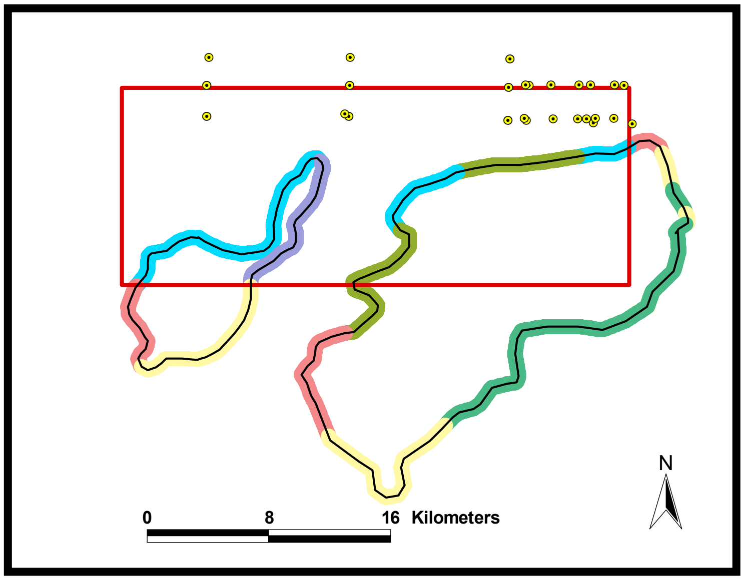


Figure 6. Location of beam trawl tows in relation to Tortugas North.

Video from 2001 and 2002 have been analyzed thus far. Because of the minimal presence of seagrass along transects, seagrass data was subsumed under macroalgae. For the reef transects, differences in percent cover among years and strata were tested with two-way ANOVA's, but no significant interactions were found (Figure 7). Coral cover varied with strata (p = 0.045), as did macroalgae (p = 0.042). The Reserve had significantly higher coral coverage (p = 0.012) while cover between Out and Park strata was not significantly different (p = 0.352). Macroalgal cover in the Park was significantly lower in the Reserve and Out strata (p = 0.016 and p = 0.059, respectively). There was no difference in coral cover across strata between years (p = 0.617), but macroalgal cover was significantly higher in 2001 (p = 0.030).

In 2001, Point Count estimates of coral species richness and diversity were significantly lower than manual visual interpretation (data not presented). To correct this problem and to facilitate species identification on the video, the filming distance was reduced from 1m to 0.4m in 2002. Richness and diversity measures were both higher in 2002 (Figure 8, richness: p =

0.002, diversity: $p < 0.001$). Richness tended toward differences among strata ($p = 0.057$) but diversity did not ($p = 0.175$).

While coral, sponges, and octocorals were occasionally found along sand transects, the percent cover was primarily bare sand, with macroalgae beginning some distance away from the reef (Figure 9). This spatial distribution of macroalgae (i.e., halo) could be due to either bioturbation or grazing pressure. In 2001, there was a strong trend towards lower macroalgal

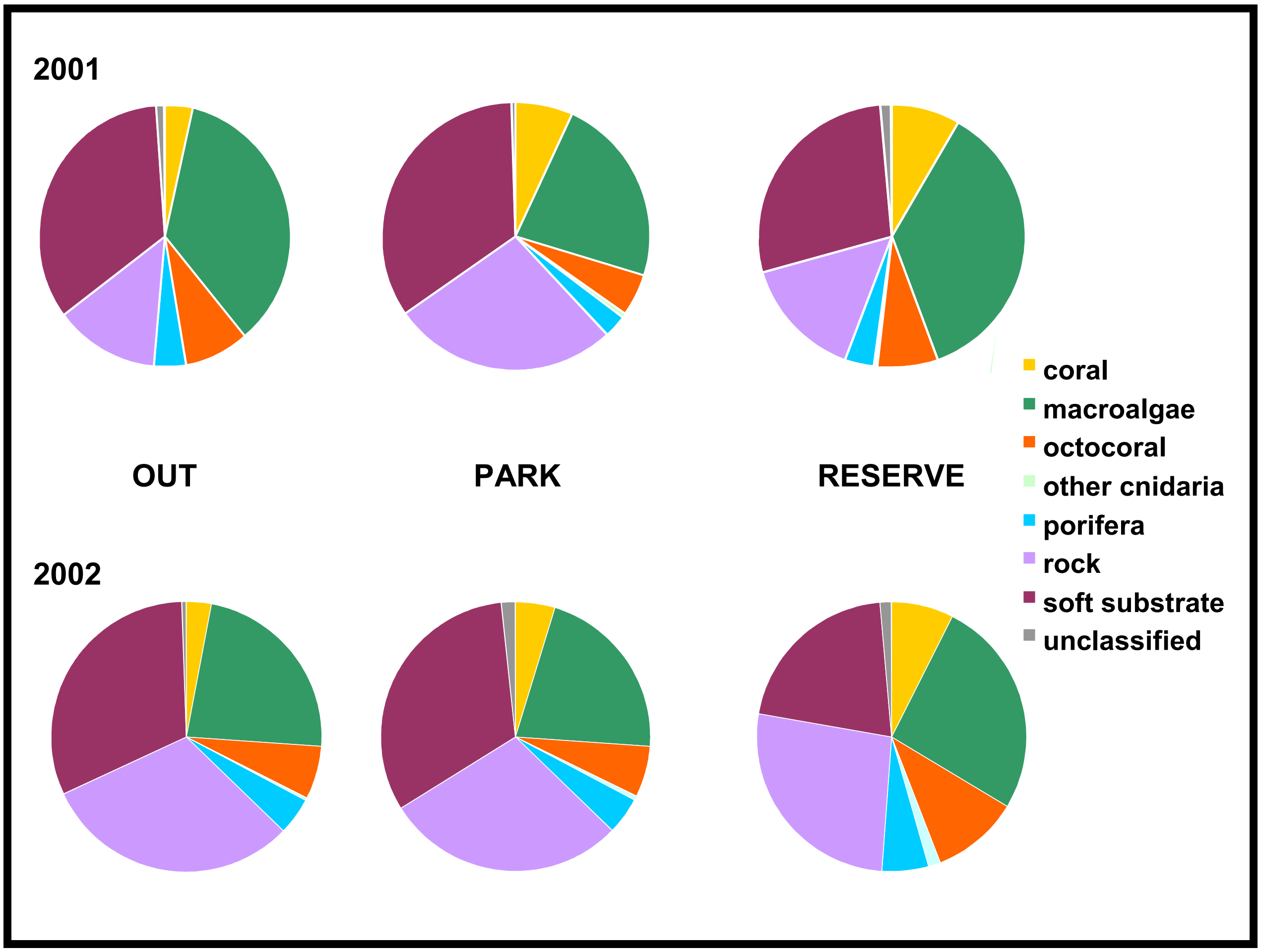


Figure 7. Percent benthic community cover for reef transects.

cover in the Park (Figure 9, Reserve > Park, $p = 0.028$; Park = Out, $p = 0.120$). However, these differences disappeared in 2002 ($p = 0.030$), likely because there was significantly less algal cover in 2002.

Coarse-Scale Mapping:

Towed Video/Sonar: SportScan images (Figure 10) were calibrated with associated video transects and the MiniBAT, with preliminary analyses confirming the placement of permanent stations at ecotones and showing agreement between diver and MiniBAT-associated video classification of habitat.

Aerial Photography: To date, two image processing procedures have been conducted on the IKONOS and QuickBird imagery: depth determination and habitat classification. Since the late 1970's scientists have been using air photos and a wide variety of digital imagery to estimate water depth. While not as accurate as sonar techniques, imagery can provide relatively accurate estimates of depth. These techniques can provide valuable information, particularly in remote areas where surveys based on sonar techniques are rare or non-existent. A ratio method of depth determination developed by Stumpf et al. (2003) was applied to both the IKONOS and QuickBird images and compared to over 28,400 DGPS referenced depth soundings recorded during a ground-truthing mission in December 2003. Error for both image sources increased with depth. For IKONOS, root mean square error (RMSE) gradually increased up to 2.1 at a depth of 16 m; after 16 m, RMSE rose rapidly, mostly due to turbidity. QuickBird did not perform as well due to an unreported problem with the green band. The algorithms of Stumpf et al. (2003) rely on a ratio of the blue and green bands to estimate depths deeper than approximately 4 m and a ratio of the blue and red bands to estimate depths between 0 and 4 m. Due to a calibration error in the green band, the blue/green ratio was affected, making depth

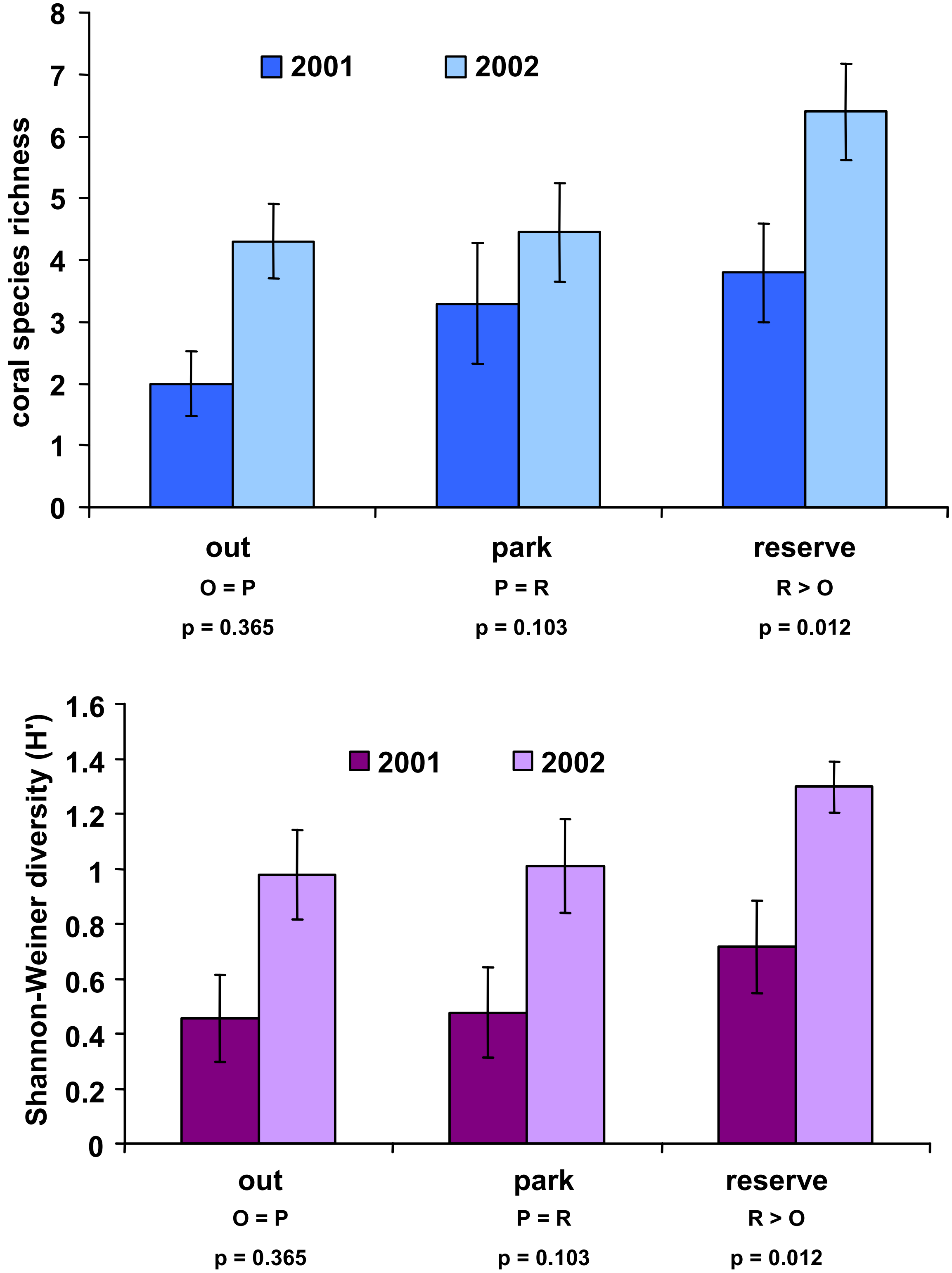


Figure 8. Mean (+/- S. E.) coral species richness and diversity. Probabilities below graphs are post-hoc Fisher's LSD tests.

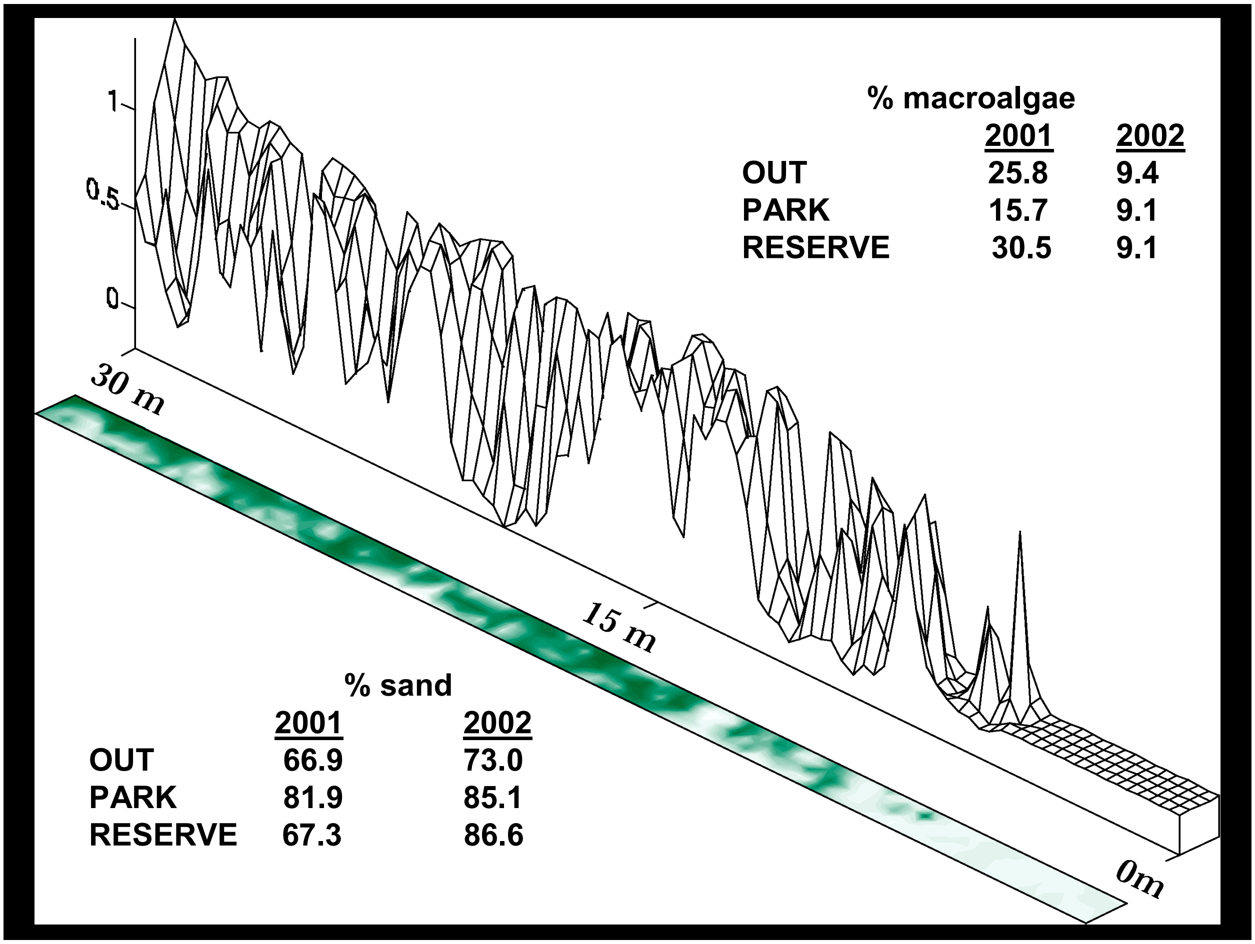


Figure 9. Mean percent cover of sand and macroalgae along sand transects. 3-D (top) and topographic (bottom) representations of macroalgae are from station RN8924 in 2001. The interface is at 0m. Notice the presence of a distinct halo out to ~ 5m.

estimates deeper than 4 m unreliable. To date we have found no mention of this problem in the literature. While the green band miscalibration causes no problems for visual interpretation, QuickBird imagery may be inadequate for users that rely on a normal blue/green relationship in studies concerning aquatic environments.

Habitat classification of IKONOS and QuickBird images, while not complete, has shown tendencies similar to other studies of coral/seagrass/algae environments (i.e., Mumby et al.,

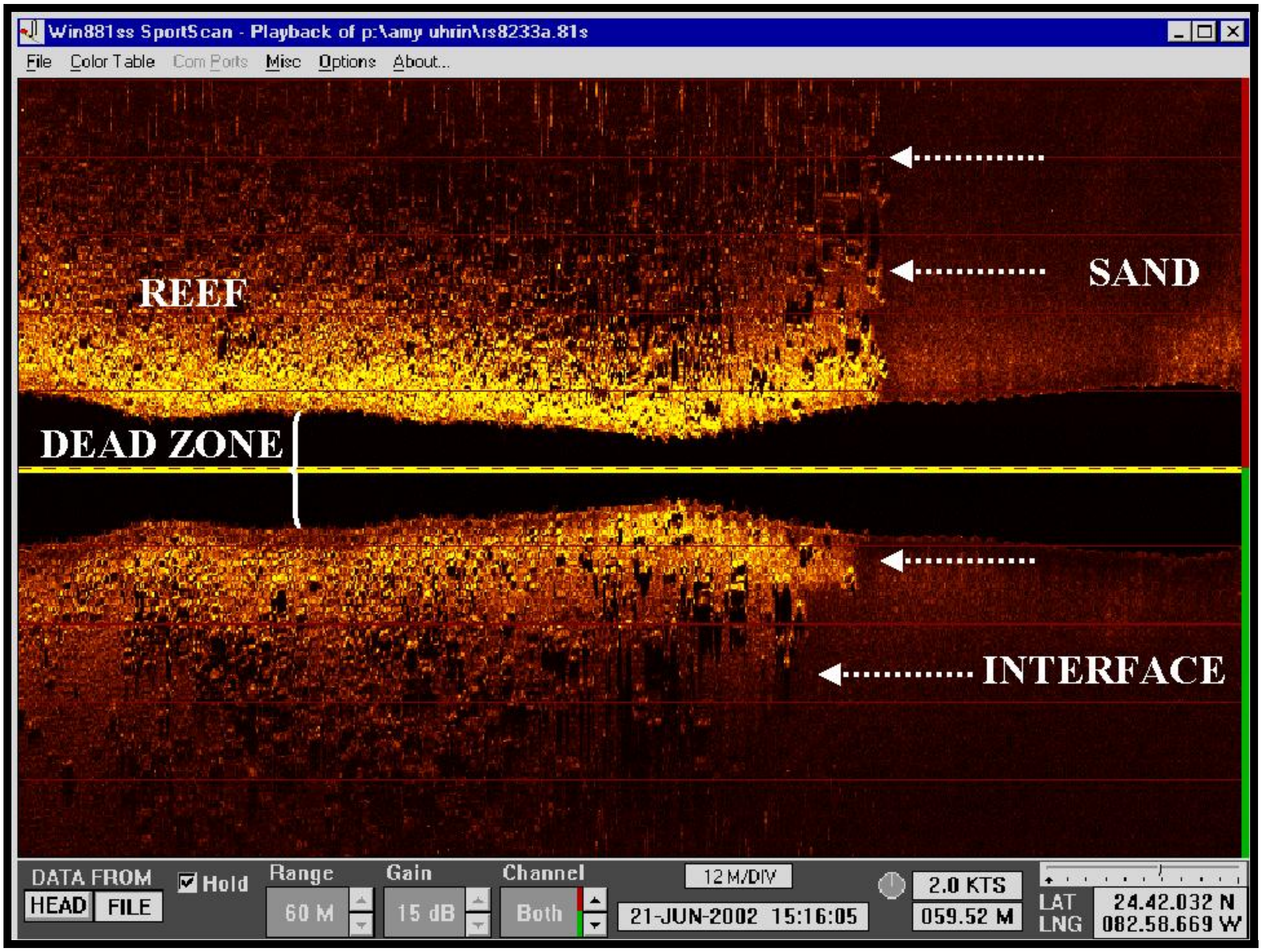


Figure 10. SportScan image of a typical interface. The "dead zone" is a blind spot that extends out at a 40° angle directly beneath the tow body.

1997, 1998). Coral and seagrass habitats as deep as 18 m can be easily visualized in the imagery. However, comparison of individual bands to the 28,400 depth soundings described above indicates that the red band only aids discrimination of bottom habitats down to 3 or 4 m. With the IR bands of both satellites essentially useless for submerged habitat discrimination, this only leaves the blue and green bands that are useful below 4 m. With only two relatively broad bands of any use below 4 m, the ability to distinguish between seagrass, algae, and coral communities based on spectra alone is limited. Initial results using Feature Analyst® automated feature extraction software (Visual Learning Systems, Inc.), an object oriented image processing system that easily allows inclusion of texture and depth to the processing stream, has aided accuracies below 4 m.

Simrad EM3000 Multibeam Echosounder: The Simrad EM3000 survey totaled approximately 500 line kilometers of multibeam data that comprised approximately 72.5 km^2 within the 30 permanent stations. Geodynamics has provided a final report containing the edited survey data with GIS compatible files depicting multibeam imagery and high-resolution 3D images of the areas encompassing the 30 stations (Figure 11). We are currently engaged in a multi-scale assessment of the multibeam data. At each station, data is clipped at three extents (30 x 30, 100 x 100, and 300 x 300m) with four resolutions per extent (0.5, 1, 3, and 10 m). Using semivariance analysis (GS+ Version 7.0, Gamma Design Software), we will examine the data to determine at which scale significant changes in habitat occur and thus at which scale biological data should be examined in order to detect changes. This process is currently underway at CCFHR.

Sediment Characterization:

Sediment particle-size is an indicator of relative wave and tidal energy at a site, and particle-size in turn influences the species composition of benthic flora and fauna found at a site. We obtained baseline data on these sediment features in order to aid our interpretation of changes in benthic communities by strata and/or over time. In 2001, sediments at all sites sampled within TER were predominantly sandy, with mean sand content ranging from 70 to 78% (Table 4). Park stations had a slightly greater silt content (mean = 22%) than Reserve and Out stations (mean = 14% and 17 %). A number of stations were sampled outside the northern boundary of TER, and sediments here were predominantly silty (Table 4).

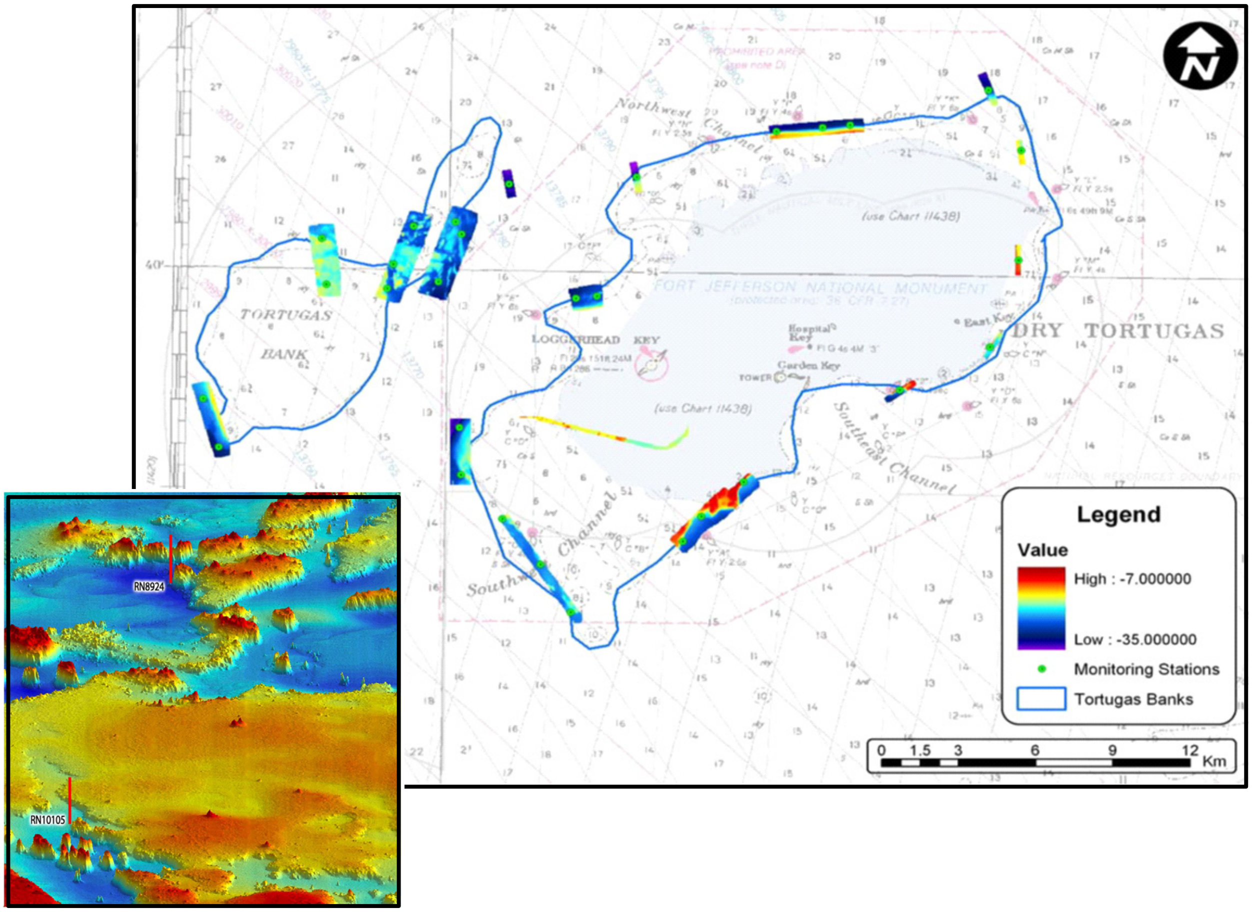


Figure 11. Simrad EM3000 bathymetric coverage over the 30 permanent stations. High resolution image encompassing sites RN10105 and RN8924 (inset)

Table 4. Sediment percent composition across TER from benthic cores extracted in 2001.

Strata	N	Parameter	Mean Percentage	Standard Error
Out	15	gravel	7.92	1.73
Out	15	sand	78.28	1.76
Out	15	silt	13.79	1.18
Park	20	gravel	7.89	1.57
Park	20	sand	69.76	2.13
Park	20	silt	22.34	2.01
Reserve	13	gravel	7.29	2.14
Reserve	13	sand	75.77	4.19
Reserve	13	silt	16.94	2.51
northern boundary	3	gravel	0.00	0.00
northern boundary	3	sand	17.35	0.81
northern boundary	3	silt	82.65	0.81

Food Web Analysis:

A sister project on the west Florida shelf (WFS) examined the food web supporting fishery organisms associated with deepwater seagrass and associated algal communities on the sandy bottom, as well as, fish from the pelagic zone and adjacent hard bottom habitats.

In Figure 12, the isotope values for various primary producers are given. Stable isotope results for fauna demonstrated that fish collected from all areas on the shelf, including pelagic and hard bottom habitats, were supported by food webs based largely upon the benthic primary producers found in the sand/seagrass community as opposed to water column constituents (Figure 13). Results from this study indicate that regions once thought to be “barren” are indeed essential fish

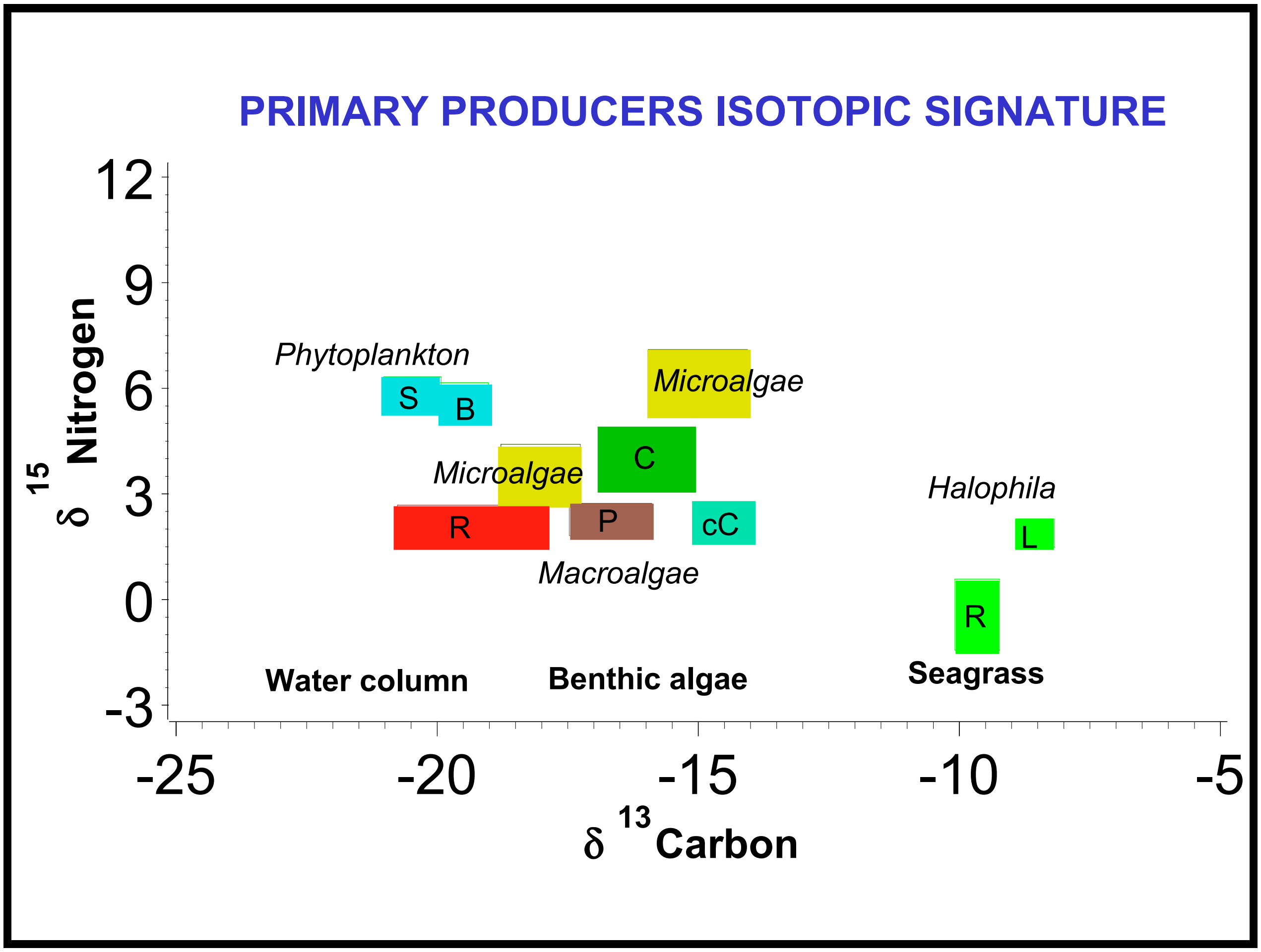


Figure 12. C and N isotope values for primary producers collected from the west Florida shelf in 1999. Boxes represent mean +/- one standard error of values for the following groups: phytoplankton (S=surface water, B=bottom water; benthic microalgae; macroalgae (R=rhodophytes, C=chlorophytes, P=phaeophytes, cC=calcareous green, and *Halophila decipiens* (L=leaves, R=root/rhizome)

habitat. The number and distribution of primary producers is more complex in TER than on the WFS, and benthic algae are components of both the reef and the interface area. The majority of the fish analyzed so far exhibit a C isotope signature of -16 or less, consistent with a food web based on benthic primary producers (Figure 14). Penaeid shrimp (Penaeidae), flounder (Bothidae) and gray snapper (Lutjanidae) samples exhibited the most enriched C values, consistent with a food web based in part on seagrass carbon. Some fish, such as red grouper

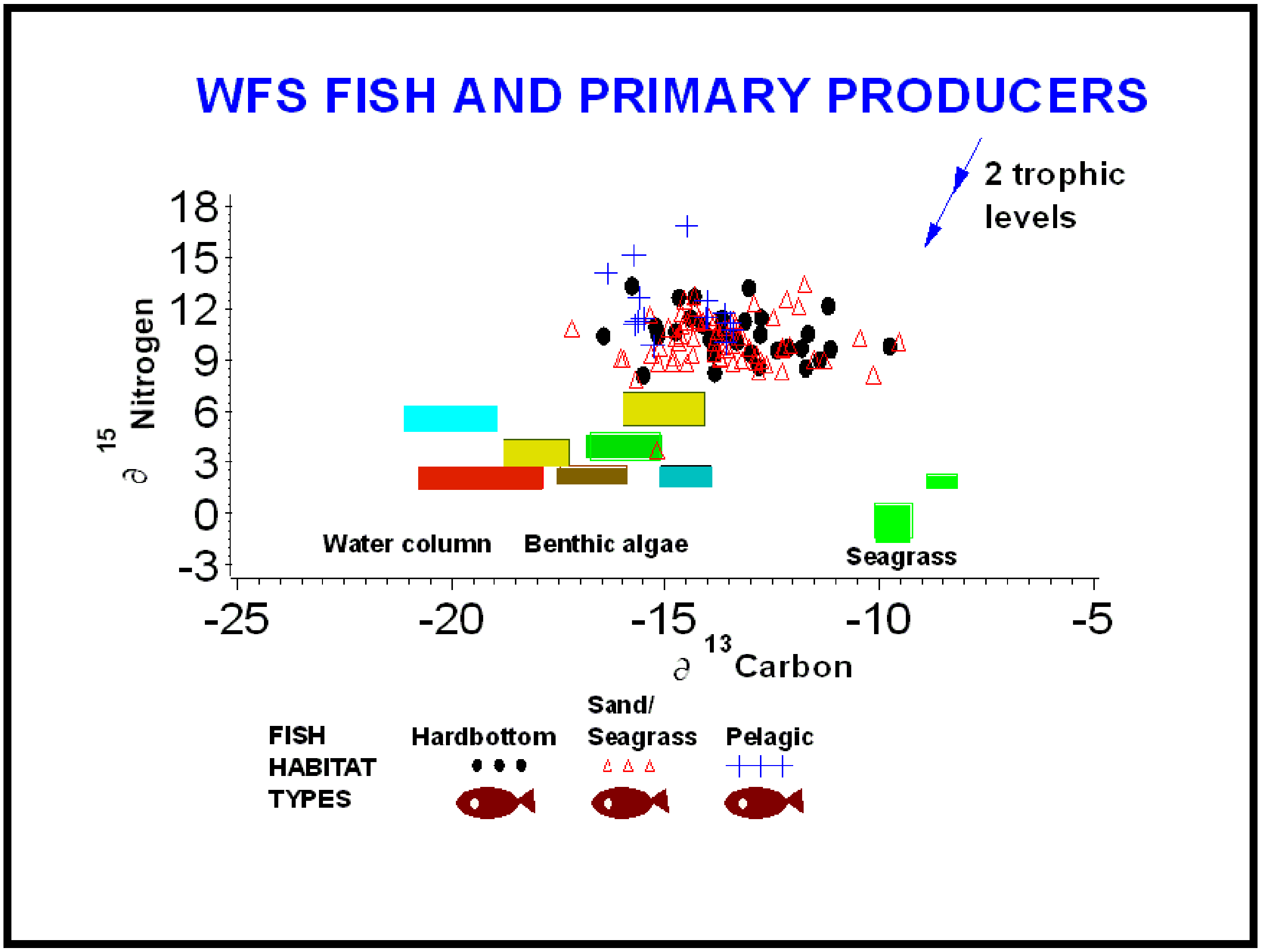


Figure 13. Comparison of stable isotope values of fish and primary producers on the west Florida shelf. Primary producers are as described in Figure 12. Fish include samples from pelagic, hardbottom, and sand/seagrass habitats. Arrows in the upper right indicate the offset expected in isotope values of an animal feeding two trophic levels above primary producers. Animals are ~ 1 and 3 / mL enriched in C and N respectively from their food sources.

(family Serranidae) and parrot fish (Scaridae) exhibited a wide range in C isotope values. Additional analyses will help us to determine whether there is a significant geographic or reserve effect on the food webs utilized by these fish.

Nitrogen isotope values are helpful in determining ontogenetic changes in fish's diets, and particularly in detecting increases in trophic level. This is due to animals preferentially

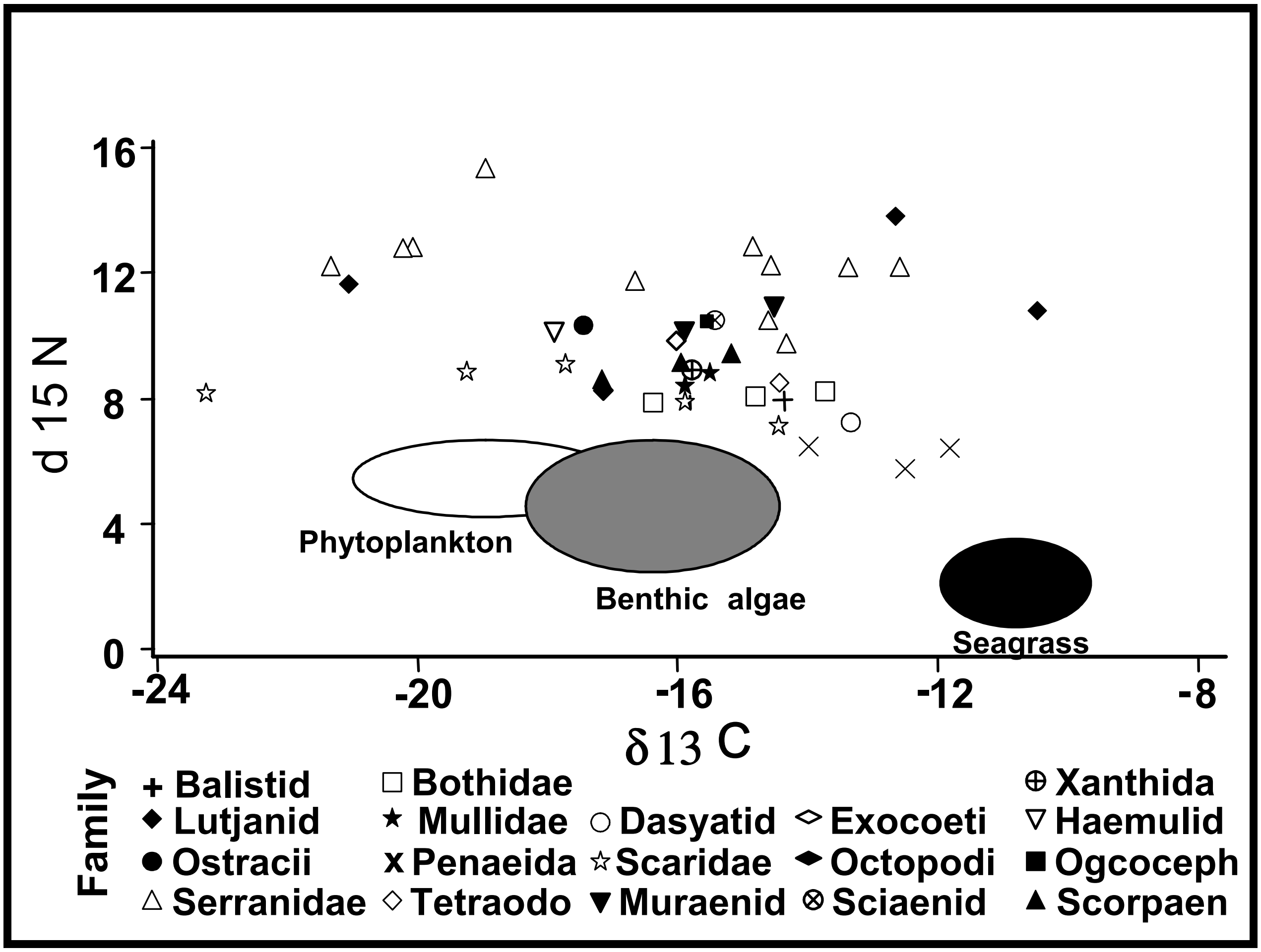


Figure 14. Carbon isotopic signatures for various fish families in TER.

retaining ^{15}N, so that there is an approximate 3 per mil increase in $d^{15}N$ per trophic level. This approach can be used to help determine whether ontogenetic diet changes include a switch from herbivory to carnivory (Cocheret de la Morineire et al., 2003). For example, the isotopic signature of red grouper (Family Serranidae) exhibits an increase in nearly 2 trophic levels as they increase in size from 25 to 70 cm.

In contrast, parrotfish (Family Scaridae) exhibit little trophic change between 8 and 25 cm length (Figure 15). These data can help to predict the potential ecosystem effects of changes in average fish size as the result of no-take regulations.

Microalgae Distributions:

Benthic chlorophyll analysis of surface sediments provides an estimate of the benthic production and microalgal food resources available at a site. Changes in benthic chlorophyll values may be due to changes in grazing pressure (top-down), or changes in light and nutrient availability (bottom-up). To examine temporal and spatial changes in benthic chlorophyll concentration, nonparametric one-way analysis of variance (ANOVA) and two-way ANOVA's were performed to test for differences in benthic microalgal biomass between year, season, strata (Out, Park and Reserve), transect location (0, 15 and 30 m) and sediment depth layer (0-1 cm and 1-3 cm). Overall, mean benthic chlorophyll concentrations were significantly different between season ($p < 0.0001$; Figure 16). As a result of this strong seasonality in benthic chlorophyll measurements, the majority of the comparisons were made using data collected during the consecutive summers of 2001-2003 (Figure 17).

Inter-annual comparisons: Both layers of surface sediment (0-1 and 1-3 cm) in the Out and Park strata demonstrated significant differences in mean summer benthic chlorophyll between years (Figure 16). In the 0-1 cm depth layer, the 15 m plot showed a significant increase between 2002 and 2003 in mean summer benthic chlorophyll ($p = 0.0086$ and 0.0105 for Out and Park, respectively). In addition, at the Park strata, mean benthic chlorophyll at the reef interface (0 m) was significantly increased in 2002 and 2003 when compared to 2001($p =$ 0.0019 and 0.0001 for 2002 and 2003, respectively). In the 1-3 cm sediment depth layer, only the reef interface (0 m) demonstrated significant differences in benthic chlorophyll between 2001

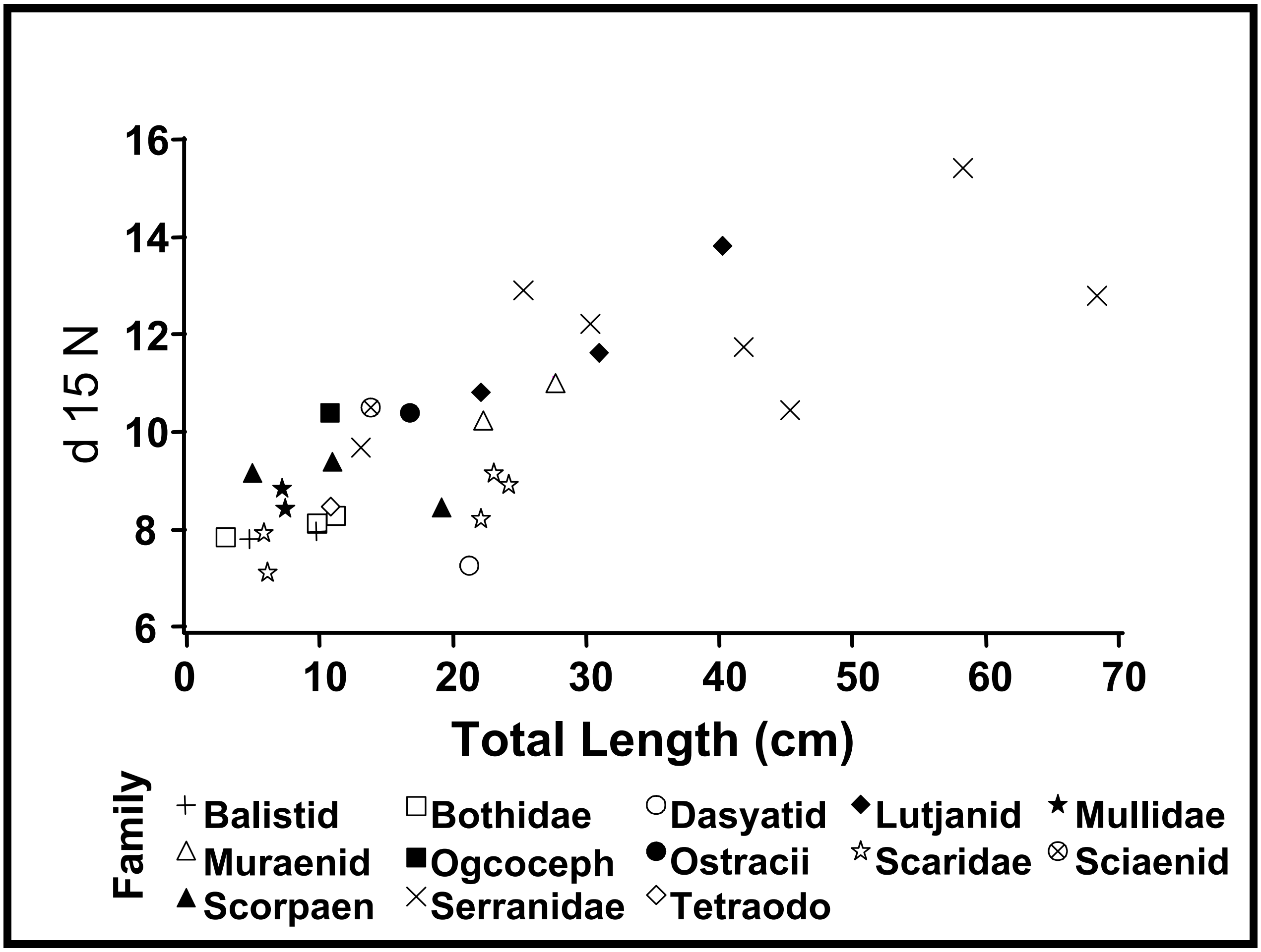


Figure 15. Nitrogen isotopic signatures (by total length) for selected fish families in TER.

and 2002 (p = 0.0153 and 0.0021 for the Out and Park strata, respectively). Contrary to the Out and Park strata, benthic chlorophyll was not significantly different between years in the Reserve strata (p values ranged from 0.0709 to 0.6062). To date, the establishment of the Reserve seems to have had no significant effect on mean annual benthic microalgal biomass during the summer.

Strata comparisons: Mean benthic chlorophyll concentrations during the summer were generally similar between the three strata, however, significant differences between strata

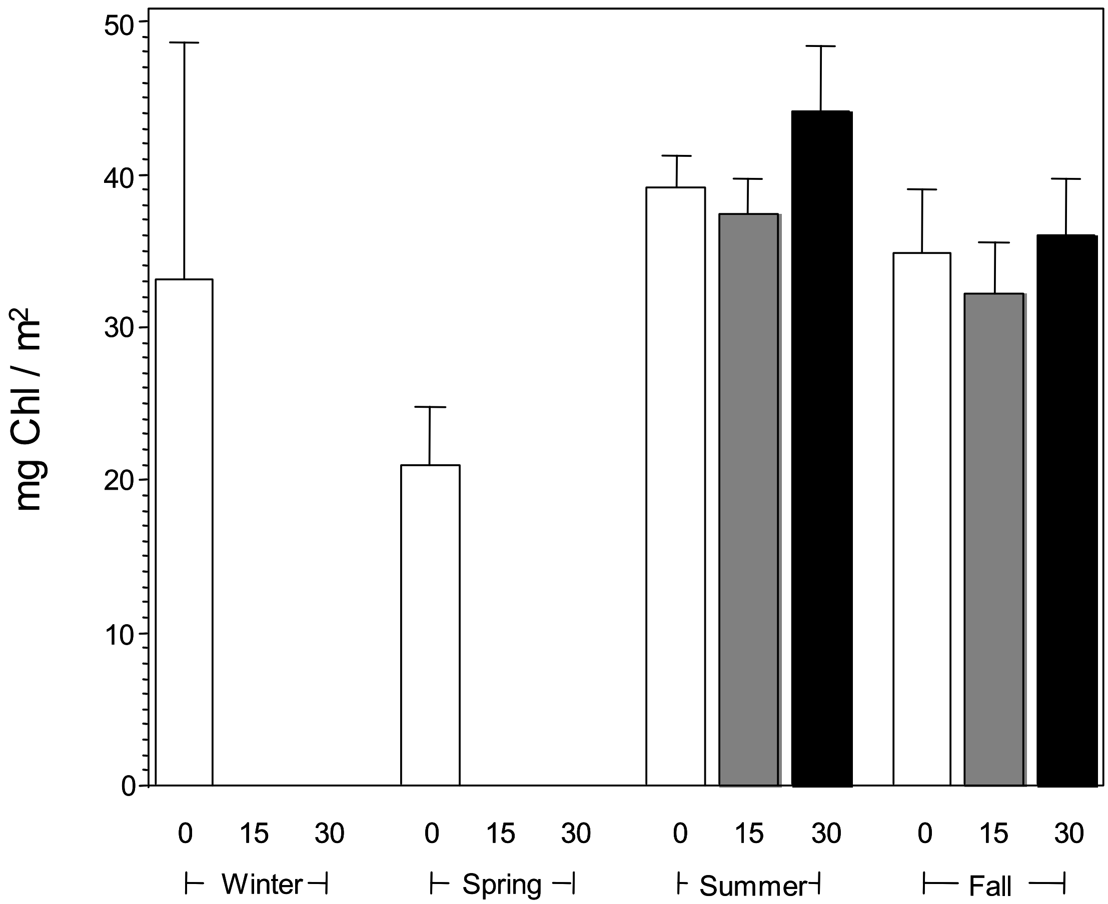


Figure 16. Mean benthic chlorophyll concentrations per season at each plot (0, 15, and 30m) along the sand transect. Winter and spring data were only collected in 2001. Fall data were only collected in 2004. Error bars represent standard deviation

were observed at the reef interface (Figure 16, plot = 0). For the 0-1 cm depth layer, mean benthic chlorophyll in the Park strata was significantly greater than that in the Out strata in 2003 ($p = 0.0175$). For the 1-3 cm depth layer, the Park strata demonstrated significantly reduced benthic chlorophyll concentrations than both the Out and Reserve strata ($p = 0.0002$).

Sediment layer and plot comparisons: As expected, summer benthic chlorophyll concentrations were significantly greater at the 0-1 cm depth layer than at the 1-3 cm depth layer.

Significant differences in summer benthic chlorophyll between plots were only observed at the Park strata in 2002. Regardless of sediment layer, this strata showed significantly higher benthic chlorophyll concentrations at the reef interface (plot = 0) than at the 15 m plot ($p = 0.0024$ and 0.0339 for the 0-1 and 1-3 cm depth layers, respectively).

There were also significant interactions between spatial and temporal parameters on mean summer benthic chlorophyll values. These interactions included strata and plot ($p = 0.0342$), year and strata ($p=0.0069$), and year and sediment layer ($p = 0.0003$).

The contribution of benthic microalgae in soft sediments adjoining coral reef habitats to reef ecosystem primary productivity has been estimated in only a few studies (Uthicke and Klumpp, 1998). These studies suggest that benthic microalgal production may contribute between 25 and 35% of reef ecosystem primary production and have emphasized the contribution of benthic microalgae in shallow reef flats and lagoons. Our results demonstrate that there is significant microalgal biomass at depths of 0-3 cm in the soft sediments at the coral reef interface, and that this community may play an important role in the food web supporting reef organisms. Previous research has demonstrated the effects of increased nutrients and changes in temperature and irradiance on the production of benthic microalgae in reef environments (Uthicke and Klumpp, 1998). We will continue to monitor this community to determine whether the imposition of TER results in any changes in the biomass of benthic microalgae occupying soft sediments near the coral reef-sandflat interface.

<u>Fish Surveys</u>:

Visual Census: To date, fish census data for the years 2001-2003 have been analyzed. Over this period, counts totaled over 50,000 fishes. Fishes counted were identified to 154 species and 12 species groups (Appendix 2). The ten most abundant species/species

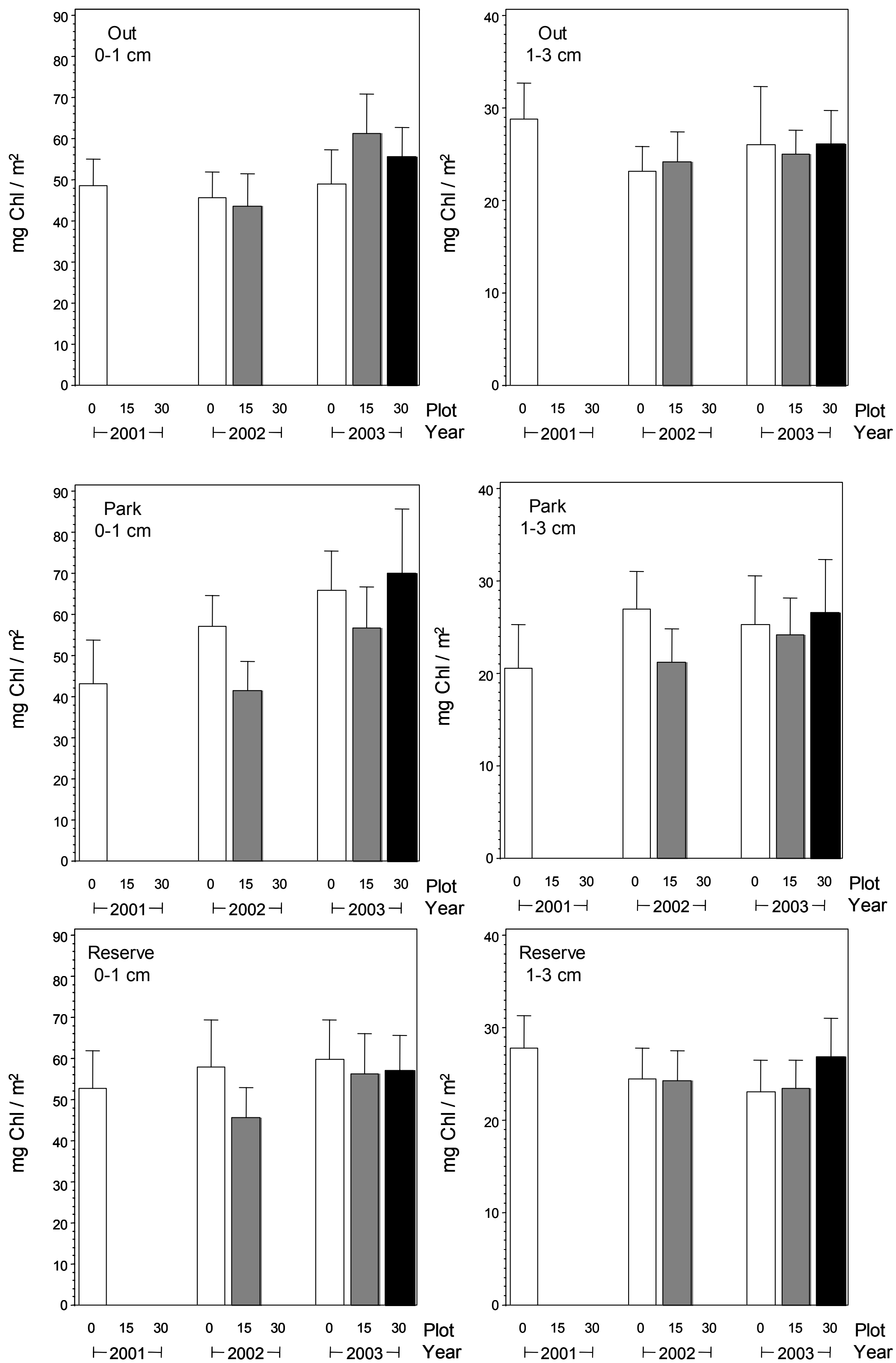


Figure 17. Mean benthic chlorophyll concentrations during the summers of 2001-2003 at the 0-1 cm sediment depth layer (left panels) and at the 1-3 cm depth layer (right panels) in each of the three strata (Out, Park, and Reserve).

groups accounted for over 80% of the total count. The most abundant species, the masked goby, accounted for 40 % of the total. The second most abundant species, comprising 10% of the total, was a mixed species group consisting of juvenile grunts (*Haemulon* sp.). Mean size for all of the ten most abundant species/species groups was less than 7.5 cm, the size assigned to fishes estimated by our visual census to be between five and ten cm in length (Appendix 2).

Overall, throughout this three year period, total number of fish was lowest in the Park strata; roughly half that observed in the Out and Reserve strata (Table 5). These between year and among strata patterns of abundance in total fish are primarily due to annual variability in recent recruits and small reef species. With few exceptions, small fish (< 10 cm total length) comprised approximately 90% of the total fish count for all year, strata, and habitat combinations (Table 6). Large fish (> 20 cm total length) made up a small proportion of total catch and variability of this proportion was relatively low among years and strata (Table 7) compared to the proportions for small fish (Table 6). For reef habitat, the proportion of large fish was relatively stable over the three years in the Park compared to the Out and Reserve strata (Table 8). In contrast for sand habitat, variability in the proportion of large fish was highest in the Park over the three year period. Additional analyses regarding species sighting frequencies (% SF) and differences in fish counts between strata and years have been completed but will not be presented here. A separate report summarizing the entire fish census data set is currently in preparation (Burke et al., in prep.). These data will then be linked with the video/still photograph habitat characterizations, once completed, to examine habitat utilization by exploited species.

Gear Impact:

Historically, the waters around the Dry Tortugas region have been the principal fishing grounds for the commercial pink shrimp fishery. With the establishment of TER, 151 square nautical miles became closed to commercial fishing activities, including pink shrimp trawling. Our faunal collections from open and protected soft bottom habitat near the northern boundary of Tortugas North strongly suggest that relaxation of trawling pressure has increased benthic biomass and diversity in this area of TER. The Reserve may act as a refuge for the large pink shrimp targeted by the fishery, and their density, as well as biomass and diversity of smaller crustaceans, is obviously higher in paired protected versus open bottom samples. Although not as obvious, differences in the fish and echinoderm assemblages between trawled and protected bottoms are likely to become clear with the detailed analysis of our samples. It appears that these soft bottom communities respond quickly to relaxation of the disturbance of trawling and we hypothesize that further changes will occur over time with development of a more stable assemblage of attached invertebrates that should develop in the more physically stable parts of the shelf.

Table 5. Total fish counts from visual census band transects in two habitats (reef and sand) within the three strata (Reserve, Park, and Out). N = 10 for each strata/substrate/year combination, for a total of 180 visual censuses.

	2001			2002			2003			
Strata	Total Count Reef	Total Count Sand	2001 Total	Total Count Reef	Total Count Sand	2002 Total	Total Count Reef	Total Count Sand	2003 Total	Grand Total
Out	14649	1114	15763	2769	222	2991	2224	638	2862	21616
Reserve	10691	191	10882	2561	96	2657	5438	139	5577	19116
Park	3128	553	3681	2658	135	2793	3198	144	3342	9816
Regional Total	28468	1858	30326	7988	453	8441	10860	921	11781	50548
Total N			60			60			60	180

Table 6. Percentage of total fish less than 10 cm total length from visual census band transects in two habitats (reef and sand) within the three strata (Reserve, Park, and Out). N = 10 for each strata/substrate/year combination, for a total of 180 visual censuses.

	REEF			SAND		
Strata	2001	2002	2003	2001	2002	2003
Out	0.963	0.919	0.908	0.970	0.964	0.983
Reserve	0.957	0.813	0.903	0.864	0.958	0.957
Park	0.890	0.953	0.910	0.787	0.881	0.993
Regional %	0.937	0.895	0.907	0.874	0.935	0.978

Table 7. Counts of fish greater than 20 cm total length from visual census band transects in two habitats (reef and sand) within the three strata (Reserve, Park, and Out). N = 10 for each strata/substrate/year combination, for a total of 180 visual censuses.

	2001			2002			2003			
Strata	Reef Count >20cm	Sand Count >20cm	2001 Total	Reef Count >20cm	Sand Count >20cm	2002 Total	Reef Count >20cm	Sand Count >20cm	2003 Total	Grand Total
Out	131	7	138	123	4	127	68	1	69	334
Reserve	154	5	159	310	4	314	265	2	267	740
Park	94	8	102	106	9	115	135	1	136	353
Regional Total	379	20	399	539	17	556	468	4	472	1427

Table 8. Percentage of total fish greater than 20 cm total length from visual census band transects in two habitats (reef and sand) within the three strata (Reserve, Park, and Out). N = 10 for each strata/substrate/year combination, for a total of 180 visual censuses.

	REEF			SAND		
Strata	2001	2002	2003	2001	2002	2003
Out	0.89	4.44	3.06	0.63	1.80	0.16
Reserve	1.44	12.10	4.87	2.62	4.17	1.44
Park	3.01	3.99	4.22	1.45	6.67	0.69
Regional %	1.33	6.75	4.31	1.08	3.75	0.43

Conclusion

This project represents a multi-disciplinary effort of previously disparate disciplines (fishery oceanography, benthic ecology, food web analysis, remote sensing, geography, landscape ecology, and resource management) and approaches (physical, biological, and ecological). Using a multi-scale approach, we have conducted an integrated Before - After Control Impact assessment of Tortugas Ecological Reserve. Our principal findings to date are:

- Highest mean coral coverage in the Reserve, but maximum coral coverage in the Park.
- Macroalgal cover lowest in the Park in 2001, but no strata differences in 2002.
- Coral species richness and diversity higher in 2002. Coral species richness trending toward differences among strata, but not significantly.
- Sand halos present at all sites, indicative of grazing pressure.
- Significant microalgal biomass, with inter-annual, seasonal, and strata variability, at depths of 0 – 3 cm in the soft sediments at the coral reef interface (and up to 30 m distance).
- Benthic chlorophyll not significantly different between years in the Reserve.
- Overall, total fish abundance lowest in the Park.
- Small fish (< 10 cm TL) comprised approximately 90% of the total fish count for all years/strata/habitat combinations.
- Proportion of large fish (> 20 cm TL) relatively stable over the three years in the Park compared to the Out and Reserve strata for reef transects.
- Variability in the proportion of large fish highest in the Park over the three year period for sand transects.

- Relaxation of trawling pressure appears to have increased benthic biomass and diversity near Tortugas North.

We expect the continuation of this effort to yield critical new information for the management of TER and the evaluation of protected areas as refuge for exploited species. There are preliminary indications that an increase in fishes and other benthic animals, including habitat-forming sessile invertebrates, are occurring in protected habitats within the Reserve. However, we do not have replicate Ecological Reserves, and differences among samples taken within TER versus those taken just outside the Reserve may conceivably be an artifact of distance from the reef and/or variations in reef topography. The final interpretation of these findings rely on completing the Before - After Control Impact sampling which will require several more years of survey.

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Appendix 1. Thirty permanent stations. Coordinates are given in decimal degrees.

Strata	Station	Latitude	Longitude	Interface Depth (ft)	Sand Depth (ft)	Reef Depth (ft)
ON	94	24 44.267976	-82 47.608944	97	98	92
ON	5527	24 36.427002	-82 59.689002	100	98	92
ON	5842	24 35.346006	-82 59.638002	85	84	75
ON	6772	24 34.357998	-82 58.671006	72	71	62
ON	11460	24 37.002006	-83 05.599002	79	78	76
OS	1864	24 42.900468	-82 46.830906	61	59	56
OS	6731	24 33.891972	-82 54.503046	80	81	75
OS	7265	24 33.330006	-82 57.768006	79	80	76
OS	7675	24 32.245002	-82 57.064002	79	78	74
OS	12379	24 35.905002	-83 05.224998	103	99	89
PN	632	24 43.433046	-82 50.785782	96	94	89
PN	690	24 43.369086	-82 51.419052	97	97	88
PN	1136	24 43.271742	-82 52.47897	99	100	81
PN	3120	24 39.46371	-82 56.563626	87	82	77
PN	3275	24 39.40581	-82 57.04923	96	94	84
PS	2780	24 40.401678	-82 46.85421	54	54	38
PS	3926	24 38.413794	-82 47.492928	68	68	58
PS	4671	24 37.407066	-82 49.550454	79	74	62
PS	6108	24 35.271246	-82 53.118654	72	73	56
PS	6493	24 34.46973	-82 54.084858	78	77	58
RN	1915	24 42.189006	-82 55.689006	100	99	85
RN	8924	24 41.005998	-83 00.814998	92	90	60
RN	9498	24 40.696002	-83 02.922006	75	78	64
RN	9807	24 39.654006	-83 02.802006	57	59	49
RN	10105	24 40.126086	-83 01.26675	83	80	64
RS	8233	24 41.990952	-82 58.628778	104	102	89
RS	9042	24 41.110998	-82 59.848002	82	78	73
RS	9162	24 40.837998	-82 59.706006	82	84	75
RS	10262	24 39.738006	-83 00.220002	91	89	78
RS	10529	24 39.575124	-83 01.398078	85	84	50

Appendix 2. Species and species groups observed during 180 visual censuses from 2001 – 2003. Fishes and groups of fishes are ranked by their total count and the percentage of the overall fish count. Mean lengths and their standard deviations are presented. Species in gray bars are considered to be especially sought after for consumptive purposes.

Rank	Common name / Species Group	Scientific Name	Family	Count	% of total	Mean length	SD length
1	masked goby	*Coryphopterus personatus*	Gobiidae	21968	43.460	3.29	0.81
2	grunt species	Haemulidae	Haemulidae	5420	10.722	3.90	1.74
3	purple reeffish	*Chromis scotti*	Pomacentridae	4381	8.667	4.40	2.40
4	bluehead wrasse	*Thalassoma bifasciatum*	Labridae	3785	7.488	5.77	2.52
5	tomtate	*Haemulon aurolineatum*	Haemulidae	1537	3.041	5.10	2.32
6	blue chromis	*Chromis cyanea*	Pomacentridae	1421	2.811	5.03	3.50
7	slippery dick	*Halichoeres bivittatus*	Labridae	856	1.693	6.00	2.71
8	striped parrotfish	*Scarus iseri*	Scaridae	850	1.682	7.10	4.92
9	yellowtail reeffish	*Chromis enchrysura*	Pomacentridae	768	1.519	4.43	2.74
10	blue goby	*Ptereleotris calliura*	Gobiidae	755	1.494	6.77	3.77
11	bicolor damselfish	*Stegastes partitus*	Pomacentridae	618	1.223	5.01	2.80
12	yellowtail snapper	*Ocyurus chrysurus*	Lutjanidae	590	1.167	17.52	7.93
13	yellowhead jawfish	*Opistognathus aurifrons*	Opistognathidae	547	1.082	5.80	2.99
14	cocoa damselfish	*Stegastes variabilis*	Pomacentridae	471	0.932	5.40	3.09
15	yellowhead wrasse	*Halichoeres garnoti*	Labridae	461	0.912	7.39	3.73
16	silversides	Antherinidae	Atherinidae	345	0.683	5.25	2.60
17	creole wrasse	*Clepticus parrae*	Labridae	306	0.605	10.44	7.47
18	brown chromis	*Chromis multilineata*	Pomacentridae	300	0.593	8.25	4.87
19	goby species	Gobiidae	Gobiidae	227	0.449	4.57	4.22
20	striped grunt	*Haemulon striatum*	Haemulidae	190	0.376	6.00	2.60
21	goldspot goby	*Gnatholepis thompsoni*	Gobiidae	182	0.360	4.73	2.12
22	french grunt	*Haemulon flavolineatum*	Haemulidae	178	0.352	17.83	6.08
23	princess parrotfish	*Scarus taeniopterus*	Scaridae	171	0.338	10.71	5.63
24	blue tang	*Acanthurus coeruleus*	Acanthuridae	166	0.328	13.28	6.85
25	threespot damselfish	*Stegastes planifrons*	Pomacentridae	164	0.324	6.53	3.09
26	spotted goatfish	*Pseudupeneus maculatus*	Mullidae	153	0.303	10.14	5.43
27	white grunt	*Haemulon plumierii*	Haemulidae	148	0.293	18.52	8.58
28	butter hamlet	**Hypoplectrus unicolor**	Serranidae	147	0.291	7.51	4.02
29	bar jack	*Carangoides ruber*	Carangidae	146	0.289	22.56	10.23
30	beaugregory	*Stegastes leucostictus*	Pomacentridae	141	0.279	4.38	1.88
31	redband parrotfish	*Sparisoma aurofrenatum*	Scaridae	136	0.269	12.96	4.42
32	sand perch	*Diplectrum formosum*	Serranidae	133	0.263	6.79	3.56
33	bluestriped grunt	*Haemulon sciurus*	Haemulidae	126	0.249	20.95	8.13
34	sunshine fish	*Chromis insolata*	Pomacentridae	113	0.224	4.65	2.14
35	blue angelfish	*Holacanthus bermudensis*	Pomacanthidae	106	0.210	22.00	10.38
36	schoolmaster	*Lutjanus apodus*	Lutjanidae	103	0.204	31.79	5.31
37	tobaccofish	*Serranus tabacarius*	Serranidae	93	0.184	7.43	4.08
38	bridled goby	*Coryphopterus glaucofraenum*	Gobiidae	90	0.178	3.00	
39	dash goby	*Ctenogobius saepepallens*	Gobiidae	89	0.176	4.60	2.37
40	gray snapper	*Lutjanus griseus*	Lutjanidae	82	0.162	29.61	7.37
41	pluma	*Calamus pennatula*	Sparidae	79	0.156	16.93	8.30
42	red grouper	*Epinephelus morio*	Serranidae	73	0.144	33.92	8.39
43	chalk bass	*Serranus tortugarum*	Serranidae	70	0.138	4.05	1.79
44	yellowtail parrotfish	**Sparisoma rubripinne**	Scaridae	69	0.137	11.66	10.39
45	reef butterflyfish	*Chaetodon sedentarius*	Chaetodontidae	67	0.133	8.45	5.87
46	foureye butterflyfish	*Chaetodon capistratus*	Chaetodontidae	66	0.131	8.81	4.71
47	neon goby	*Elacatinus oceanops*	Gobiidae	62	0.123	3.23	1.01
48	spotfin butterflyfish	*Chaetodon ocellatus*	Chaetodontidae	62	0.123	12.84	6.87
49	stoplight parrotfish	*Sparisoma viride*	Scaridae	60	0.119	16.67	8.34
51	hogfish	*Lachnolaimus maximus*	Labridae	56	0.111	28.57	7.71
52	squirrelfish	*Holocentrus adscensionis*	Holocentridae	55	0.109	19.77	7.76
53	blue parrotfish	*Scarus coeruleus*	Scaridae	54	0.107	11.50	10.63
54	sharpnose puffer	*Canthigaster rostrata*	Tetraodontidae	53	0.105	6.55	3.30
55	round scad	*Decapterus punctatus*	Carangidae	50	0.099	15.00	
56	gray angelfish	*Pomacanthus arcuatus*	Pomacanthidae	49	0.097	27.83	8.07
57	saucereye porgy	*Calamus calamus*	Sparidae	47	0.093	15.87	9.84
58	yellow goatfish	*Mulloidichthys martinicus*	Mullidae	47	0.093	24.17	8.78
59	doctorfish	*Acanthurus chirurgus*	Acanthuridae	45	0.089	17.52	9.25
60	longspine squirrelfish	*Holocentrus rufus*	Holocentridae	43	0.085	17.50	5.59
61	blue hamlet	**Hypoplectrus gemma**	Serranidae	37	0.073	8.45	4.47

62	harlequin bass	*Serranus tigrinus*	Serranidae	34	0.067	6.82	3.84
63	ocean surgeonfish	*Acanthurus bahianus*	Acanthuridae	34	0.067	17.08	6.79
64	queen angelfish	*Holacanthus ciliaris*	Pomacanthidae	33	0.065	18.01	10.13
Rank	**Common name / Species Group**	**Scientific Name**	**Family**	**Count**	**% of total**	**Mean length**	**SD length**
65	barred hamlet	*Hypoplectrus puella*	Serranidae	32	0.063	8.72	4.07
66	bluelip parrotfish	*Cryptotomus roseus*	Scaridae	30	0.059	3.75	1.59
67	parrotfish species	Scaridae	Scaridae	30	0.059	10.05	5.13
68	black grouper	*Mycteroperca bonaci*	Serranidae	28	0.055	36.43	4.96
69	greenblotch parrotfish	*Sparisoma atomarium*	Scaridae	28	0.055	5.10	2.26
70	scamp	*Mycteroperca phenax*	Serranidae	27	0.053	23.09	9.48
71	graysby	*Cephalopholis cruentata*	Serranidae	25	0.049	19.02	8.42
72	spanish hogfish	*Bodianus rufus*	Labridae	25	0.049	18.55	9.99
73	dusky damselfish	*Stegastes adustus*	Pomacentridae	24	0.047	7.09	0.58
74	mutton snapper	*Lutjanus analis*	Lutjanidae	23	0.046	33.86	6.55
75	yellow jack	*Carangoides bartholomaei*	Carangidae	23	0.046	37.50	3.54
76	smallmouth grunt	*Haemulon chrysargyreum*	Haemulidae	20	0.040	7.50	
77	orangespotted goby	*Nes longus*	Gobiidae	19	0.038	7.13	5.24
78	sergeant major	*Abudefduf saxatilis*	Pomacentridae	18	0.036	8.10	1.34
79	twospot cardinalfish	*Apogon pseudomaculatus*	Apogonidae	18	0.036	4.50	2.32
80	hovering goby	*Ptereleotris helenae*	Gobiidae	17	0.034	4.08	1.86
81	saddled blenny	*Malacoctenus triangulatus*	Clinidae	17	0.034	5.25	2.35
82	sand diver	*Synodus intermedius*	Synodontidae	16	0.032	10.33	12.70
83	sand tilefish	*Malacanthus plumieri*	Malacanthidae	16	0.032	26.30	10.03
84	banded butterflyfish	*Chaetodon striatus*	Chaetodontidae	15	0.030	10.04	8.93
85	rock beauty	*Holacanthus tricolor*	Pomacanthidae	14	0.028	16.09	10.51
86	bandtail puffer	*Sphoeroides spengleri*	Tetraodontidae	13	0.026	8.10	4.07
87	cottonwick	*Haemulon melanurum*	Haemulidae	12	0.024	7.50	
88	black hamlet	*Hypoplectrus nigricans*	Serranidae	11	0.022	8.67	3.88
89	hamlet species	*Hypoplectrus sp.*	Serranidae	11	0.022	7.63	4.04
90	bigeye scad	*Selar crumenophthalmus*	Carangidae	10	0.020	19.63	19.44
91	cleaning goby	**Gobiosoma genie**	Gobiidae	10	0.020	3.00	
92	coney	*Cephalopholis fulva*	Serranidae	10	0.020	23.33	6.96
93	french angelfish	*Pomacanthus paru*	Pomacanthidae	10	0.020	28.33	8.61
94	great barracuda	*Sphyraena barracuda*	Sphyraenidae	10	0.020	40.00	
95	gag grouper	*Mycteroperca microlepis*	Serranidae	9	0.018	32.50	6.27
96	midnight parrotfish	*Scarus coelestinus*	Scaridae	9	0.018	36.00	6.52
97	damselfish species	Pomacentridae	Pomacentridae	8	0.016	7.50	
98	horse-eye jack	*Caranx latus*	Carangidae	8	0.016	40.00	
99	barred blenny	*Hypleurochilus bermudensis*	Blenniidae	7	0.014	6.00	2.12
100	bucktooth parrotfish	*Sparisoma radians*	Scaridae	7	0.014	6.00	2.60
101	red hind	*Epinephelus guttatus*	Serranidae	7	0.014	23.00	9.25
102	seminole goby	*Microgobius carri*	Gobiidae	7	0.014	3.64	
103	smooth trunkfish	*Lactophrys triqueter*	Ostraciidae	7	0.014	14.00	7.20
104	almaco jack	*Seriola rivoliana*	Carangidae	6	0.012	35.00	8.66
106	rainbow wrasse	*Halichoeres pictus*	Labridae	6	0.012	5.25	3.18
107	blenny species	Blenniidae	Clinidae	5	0.010	4.13	2.25
108	gray triggerfish	*Balistes capriscus*	Balistidae	5	0.010	32.50	8.66
109	jawfish species	Opistognathidae	Opistognathidae	5	0.010	7.50	
110	redtail parrotfish	*Sparisoma chrysopterum*	Scaridae	5	0.010	28.75	5.30
111	reef croaker	*Odontoscion dentex*	Sciaenidae	5	0.010	15.00	
112	singlespot frogfish	*Antennarius radiosus*	Antennaridae	5	0.010	25.00	
113	wrasse basslet	**Liopropoma eukrines**	Serranidae	5	0.010	9.38	3.75
114	clown wrasse	*Halichoeres maculipinna*	Labridae	4	0.008	3.00	0.00
115	green razorfish	*Xyrichtys splendens*	Labridae	4	0.008	5.25	3.18
116	lane snapper	*Lutjanus synagris*	Lutjanidae	4	0.008	11.25	5.30
117	mahogany snapper	*Lutjanus mahogoni*	Lutjanidae	4	0.008	26.88	
118	tattler bass	*Serranus phoebe*	Serranidae	4	0.008	5.25	2.60
119	wrasse blenny	*Hemiemblemaria simulus*	Clinidae	4	0.008	4.13	2.25
120	yellowline goby	*Elacatinus horsti*	Gobiidae	4	0.008	3.00	
121	dusky flounder	*Syacium papillosum*	Bothidae	3	0.006	7.50	
122	dusky jawfish	*Opistognathus whitehursti*	Opistognathidae	3	0.006	12.50	4.33
123	orangeback bass	*Serranus annularis*	Serranidae	3	0.006	7.50	
124	scrawled filefish	*Aluterus scriptus*	Balistidae	3	0.006	37.50	4.33
125	shortfin pipefish	*Cosmocampus elucens*	Syngnathidae	3	0.006	3.00	
126	spanish grunt	*Haemulon macrostomum*	Haemulidae	3	0.006	21.67	12.83

127	white margate	**Haemulon album**	Haemulidae	3	0.006	32.50	7.50
128	yellowcheek wrasse	*Halichoeres cyanocephalus*	Labridae	3	0.006	4.50	2.60
129	ceasar grunt	*Haemulon carbonarium*	Haemulidae	2	0.004	25.00	
130	cero mackerel	*Scomberomorus regalis*	Scombridae	2	0.004	40.00	
131	hairy blenny	*Labrisomus nuchipinnis*	Clinidae	2	0.004	3.00	
132	inshore lizardfish	*Synodus foetens*	Synodontidae	2	0.004	11.25	5.30
133	lefteye flounder	Bothiidae	Bothidae	2	0.004	20.00	
Rank	**Common name / Species Group**	**Scientific Name**	**Family**	**Count**	**% of total**	**Mean length**	**SD length**
134	nurse shark	*Ginglymostoma cirratum*	Orectolobidae	2	0.004	40.00	
135	sharknose goby	*Elacatinus evelynae*	Gobiidae	2	0.004	3.00	
136	trumpetfish	*Aulostomus maculatus*	Aulostomidae	2	0.004	20.00	7.07
137	amberjack	**Seriola dumerili**	Carangidae	1	0.002	40.00	
138	banded jawfish	Engraulidae	Opistognathidae	1	0.002	7.50	
139	barred cardinalfish	*Opistognathus macrognathus*	Apogonidae	1	0.002	7.50	
140	belted sandfish	*Serranus subligarius*	Serranidae	1	0.002	3.00	
141	colon goby	*Coryphopterus dicrus*	Gobiidae	1	0.002	3.00	
142	cubbyu	*Pareques umbrosus*	Sciaenidae	1	0.002	15.00	
143	dog snapper	*Lutjanus jocu*	Lutjanidae	1	0.002	40.00	
144	eyed flounder	*Bothus ocellatus*	Bothidae	1	0.002	15.00	
145	fairy basslet	*Gramma loreto*	Grammatidae	1	0.002	3.00	
146	filefish	Balistidae	Balistidae	1	0.002	3.00	
147	fringed filefish	*Monacanthus ciliatus*	Balistidae	1	0.002	3.00	
148	goldentail moray	*Gymnothorax miliaris*	Muraenidae	1	0.002	40.00	
149	honeycomb cowfish	*Acanthostracion polygonius*	Ostraciidae	1	0.002	32.50	
150	indigo hamlet	*Hypoplectrus indigo*	Serranidae	1	0.002	15.00	
151	longfin damselfish	*Stegastes diencaeus*	Pomacentridae	1	0.002	3.00	
152	permit	*Trachinotus falcatus*	Carangidae	1	0.002	40.00	
153	porcupinefish	*Diodon hystrix*	Tetraodontidae	1	0.002	32.50	
154	puffer species	Tetraodontidae	Tetraodontidae	1	0.002	3.00	
155	queen triggerfish	*Balistes vetula*	Balistidae	1	0.002	7.50	
156	redspotted hawkfish	*Amblycirrhitus pinos*	Cirrhitidae	1	0.002	3.00	
157	reticulate moray	*Muraena retifera*	Muraenidae	1	0.002	40.00	
158	rock hind	*Epinephelus adscenisonis*	Serranidae	1	0.002	32.50	
159	rosy blenny	*Malacoctenus macropus*	Clinidae	1	0.002	3.00	
161	sailors choice	*Haemulon parra*	Haemulidae	1	0.002	3.00	
162	sharksucker	*Echeneis naucrates*	Echeneidae	1	0.002	40.00	
163	spotted moray	*Gymnothorax moringa*	Muraenidae	1	0.002	40.00	
164	yellowfin grouper	*Mycteroperca venenosa*	Serranidae	1	0.002	40.00	
165	yellowtail damselfish	*Microspathodon chrysurus*	Pomacentridae	1	0.002	7.50	

United States Department of Commerce

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